四川大学 SICHUAN UNIVERSITY

先进空间结构研究小组

负责人：安宁

四川大学航空航天工程系

空间先进机构与智能飞行器教育部重点实验室

2025. 06. 30

研究方向速览

- **先进空间结构**：**可展开结构**，**碳纤维复合材料**，薄壁结构，薄膜结构，**力学超材料**，折纸/剪纸超材料，软体机器人；
- **智能化**：人工智能与机器学习，**数据驱动**，代理模型，降阶计算，**数字孪生**，AI for Science；
- **设计**：超材料，可展开结构设计，**机构设计**；
- **优化**：结构优化（尺寸/形状/拓扑），遗传算法，**编程语言**；
- **科学**：**固体力学**，**计算流体力学**，人工智能**新算法**；
- **技术**：**有限元**，自主研发/二次开发，**智能优化结构设计平台**。

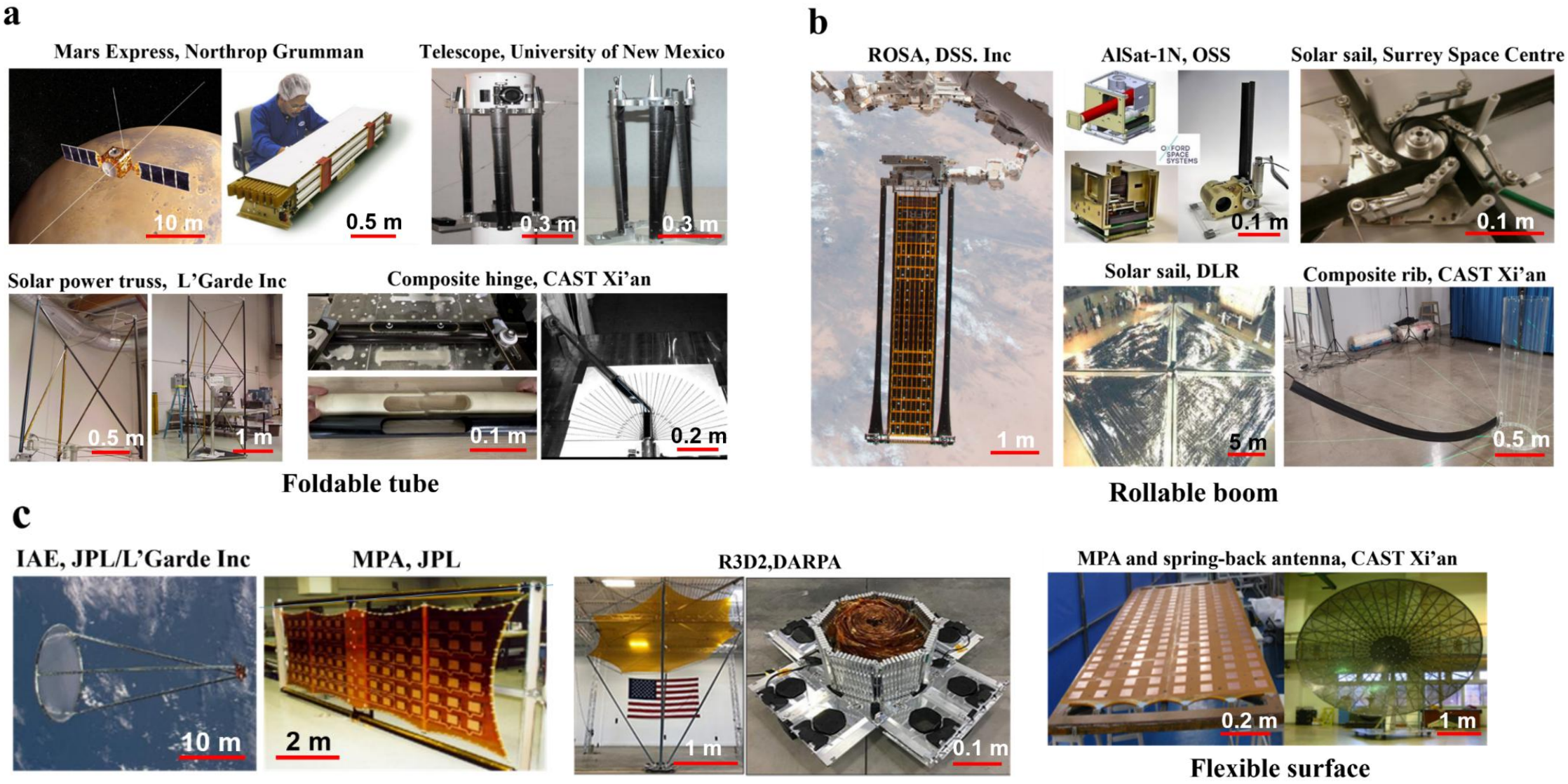
负责人简介

安宁 四川大学副研究员、研究生导师

- 2010.9-2020.6，西安交大，本硕博，航空宇航科学与技术
- 2017.9-2019.9，哈佛大学，联合培养博士，力学
- 2021.9-至今，四川大学，副研究员、硕士生导师，航空航天力学与工程
- 2025.8-，意大利特伦托大学，力学与航空航天，访问学者

- 负责国家/四川省自然科学基金、各类企业横向课题等科研项目**10**余项；发表SCI论文**30**余篇，总引用**1500**余次；
  - 指导本科毕业生**9**名；在读研究生**3**名、本科毕设生**3**名、科研训练学生若干。
  - 其他：2022年获得西安交通大学优秀博士学位论文、同年入选成都市天府海智计划专家，2024年入选国家自然科学基金委“中欧人才项目”，2025年入选国家留学基金委访问学者项目，担任**5**本中英文SCI/EI期刊青年编委。

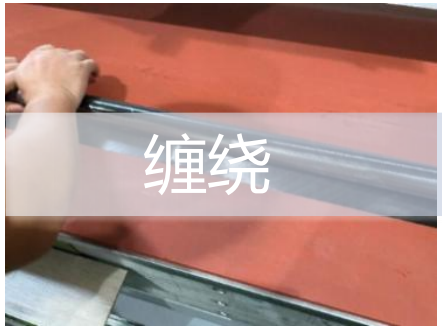
可展开空间结构

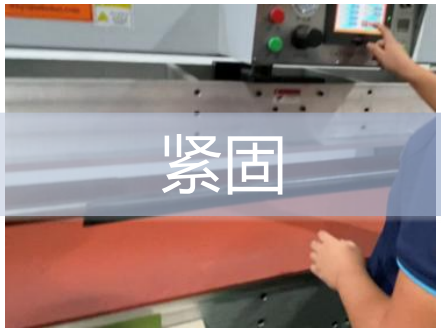


Ma, X.*, **An, N.,** et al. (2024) Design, modeling, and manufacturing of high strain composites for space deployable structures. *Communications Engineering*, 3(1), 78. **Nature旗下综述文章**

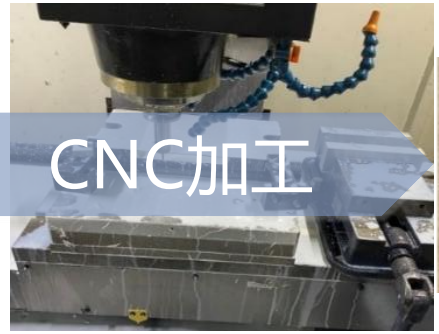
复合材料铰链折叠展开分析

➢ 复合材料圆管铰链加工及试验

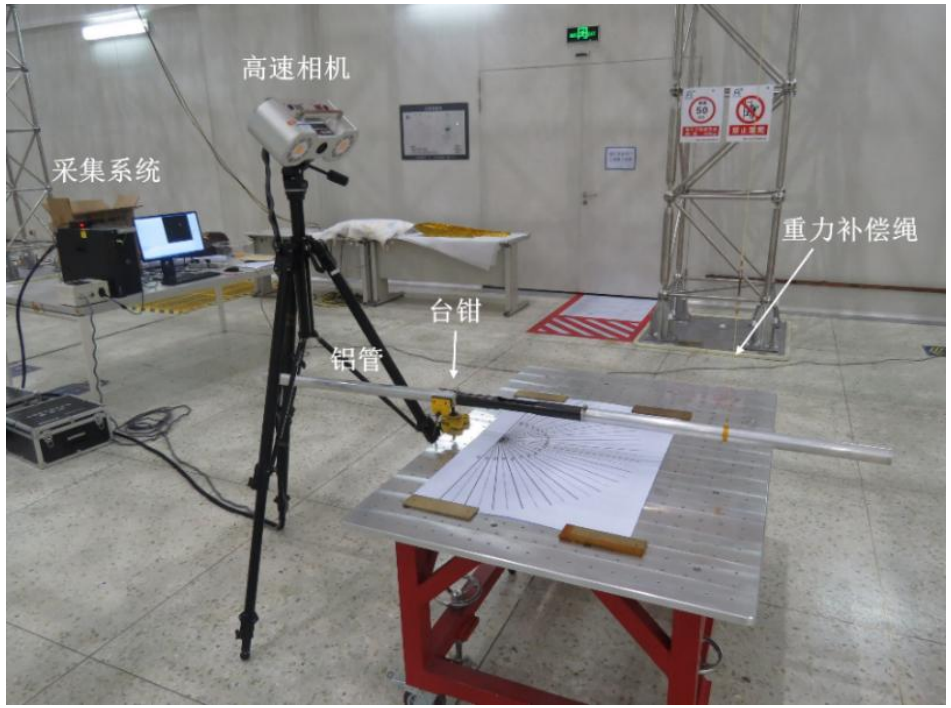

缠绕


紧固

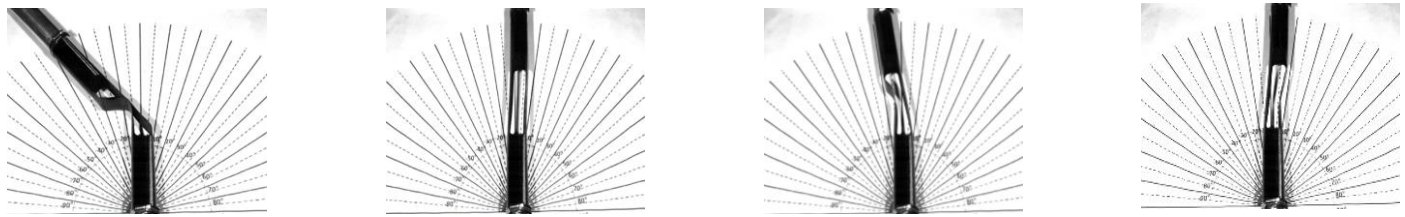

固化


CNC加工

铰链成品



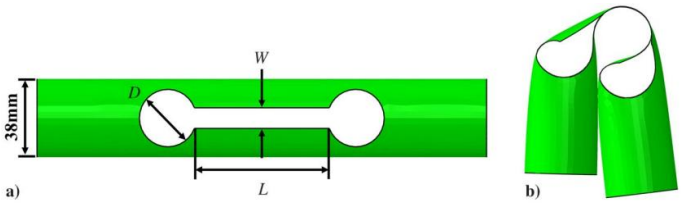
仿真模型

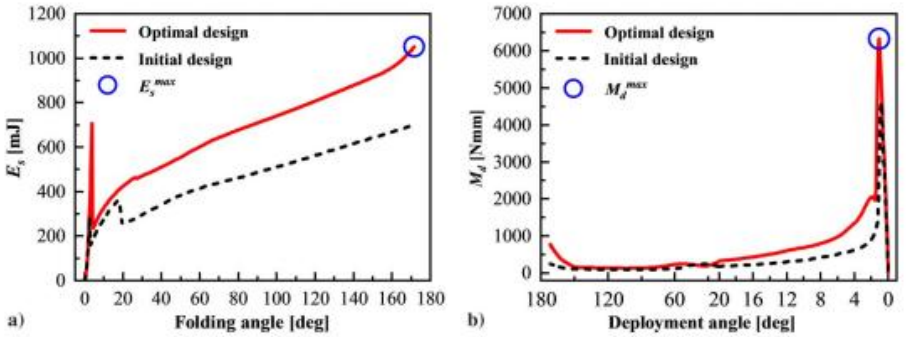


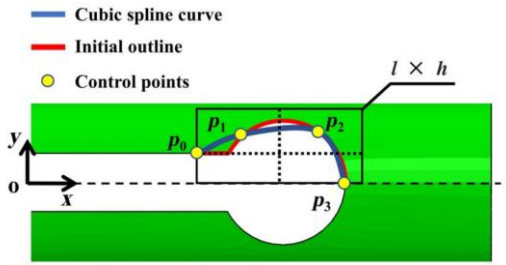
试验结果

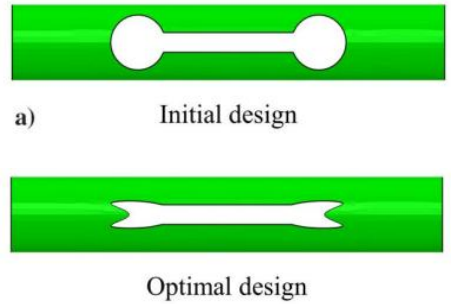
复合材料铰链切口形状优化

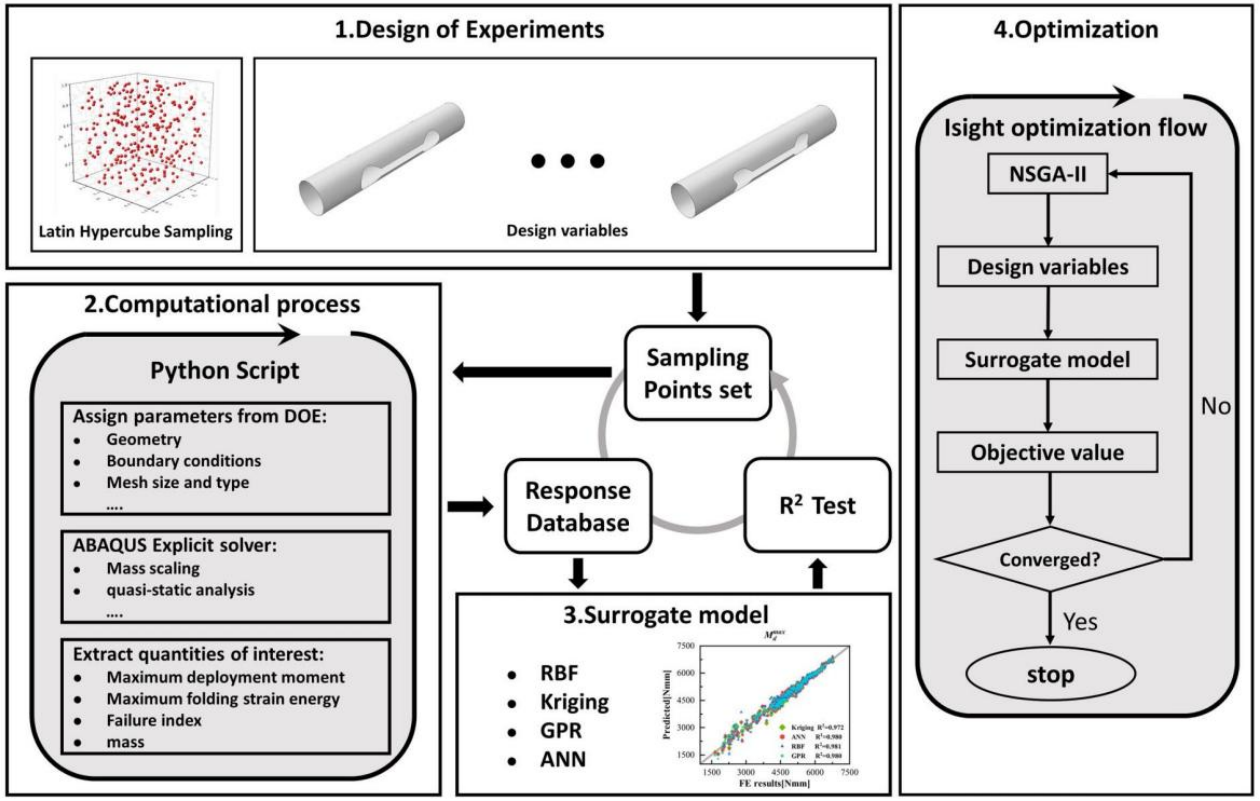
- **机器学习+有限元+优化算法**







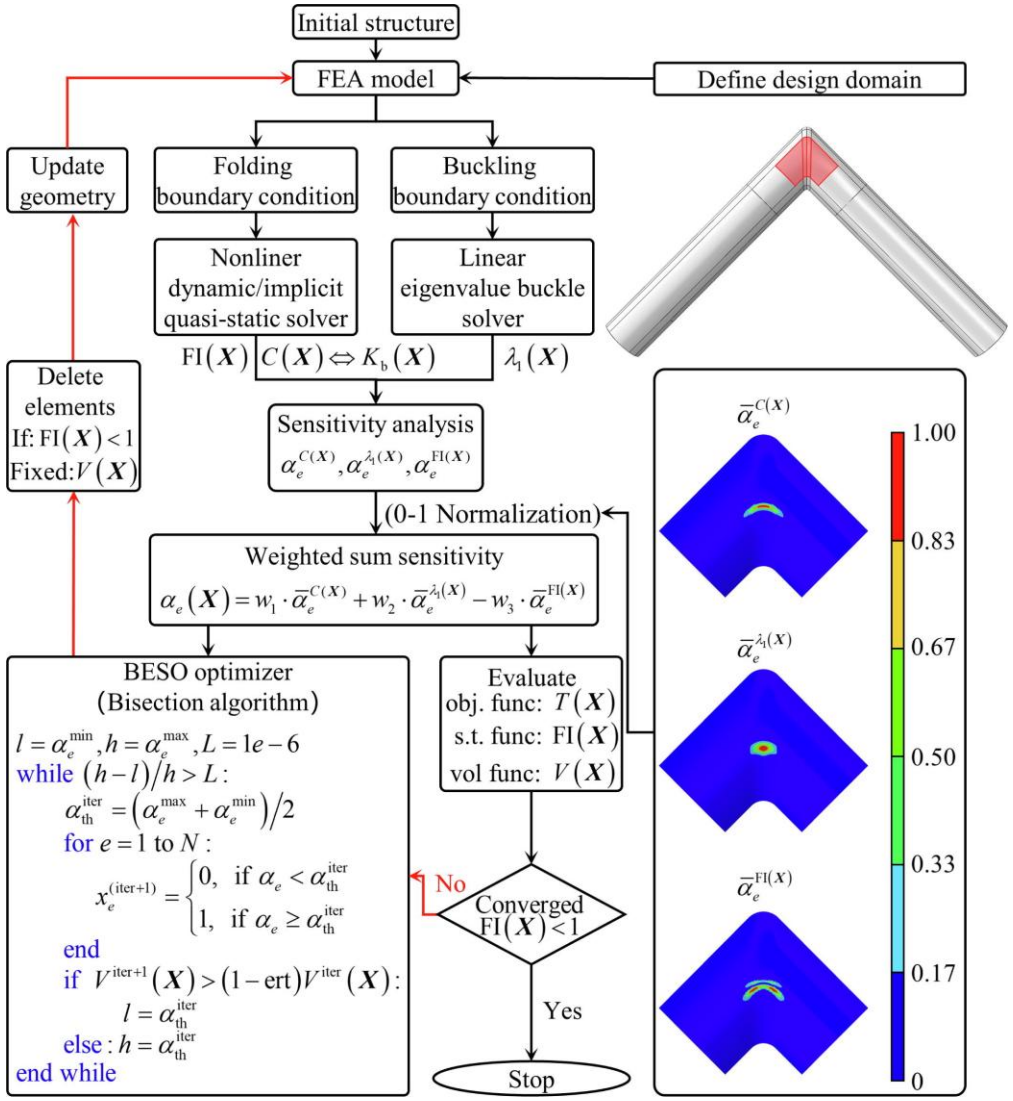


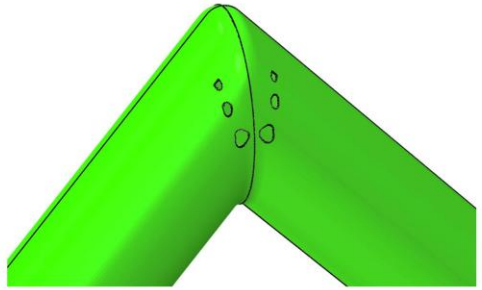


Jin, H., Jia, Q., **An, N.***, Zhao, G., Ma, X. and Zhou, J.*, 2022. AIAA Journal, 60(10), pp.5942-5953.

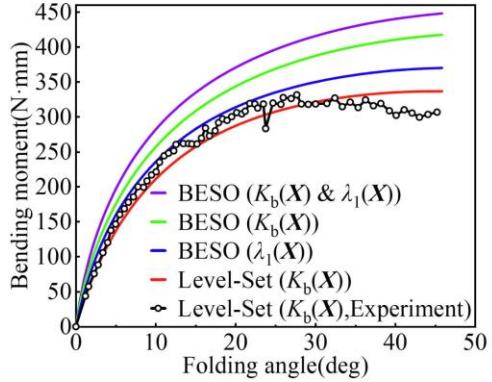
复合材料铰链拓扑优化

➢ 90°直角圆管铰链拓扑优化

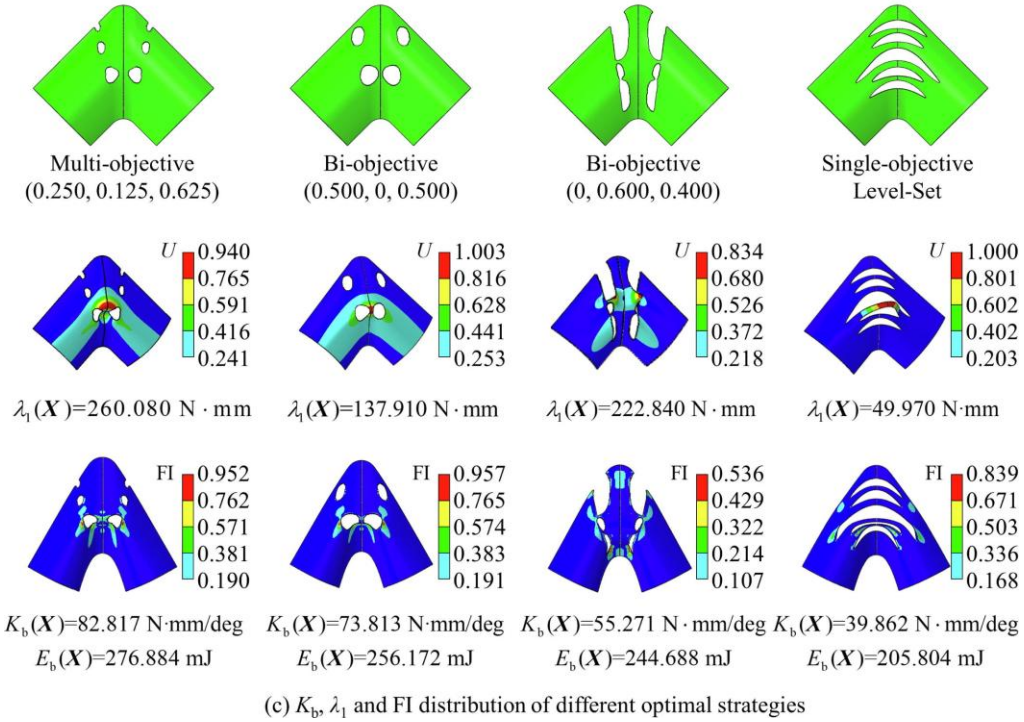




(a) Optimal design from multi-objective



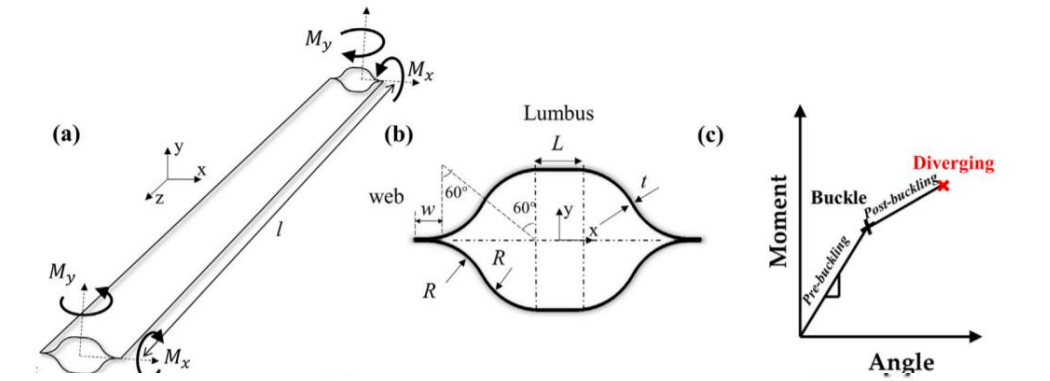
(b) Folding angle-moment curves

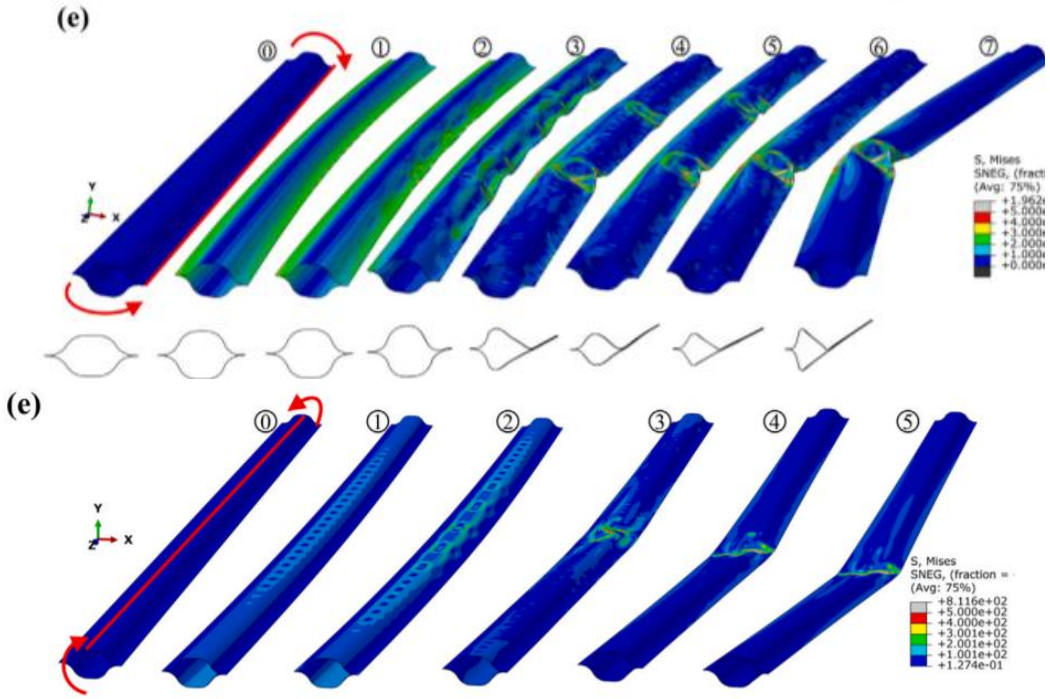


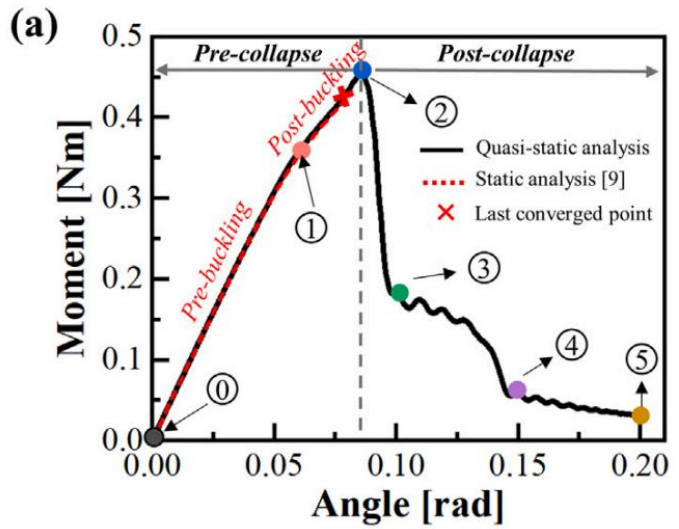
(c) K_b, λ_1 and FI distribution of different optimal strategies

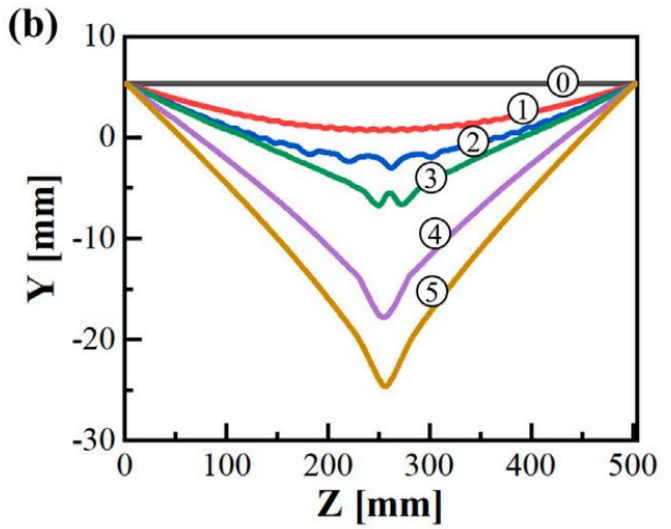
Jin, H., **An, N.***, Jia, Q., Shao, C., Ma, X., & Zhou, J.* (2025). *Chinese Journal of Aeronautics*, 103530.

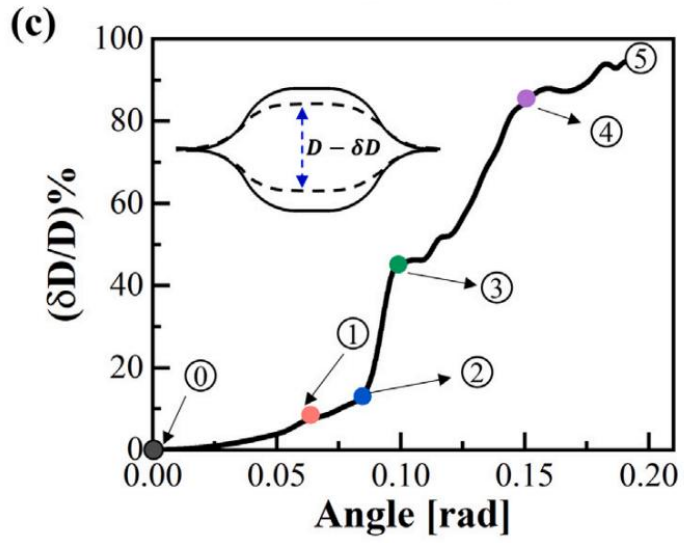
复合材料豆荚杆力学稳定性分析

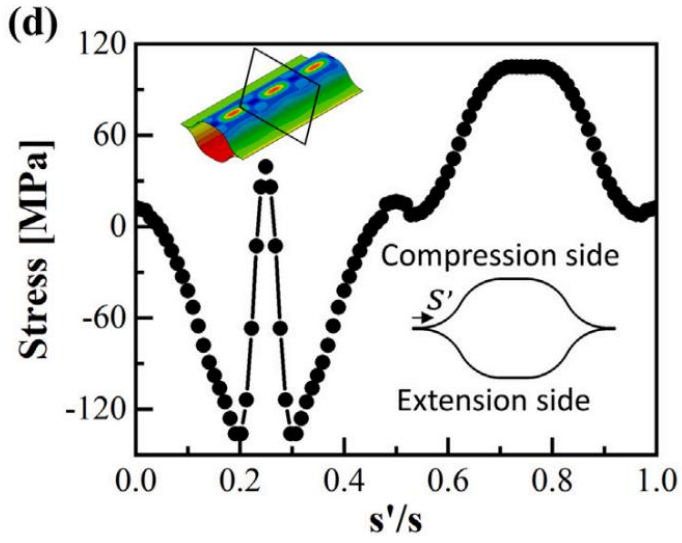












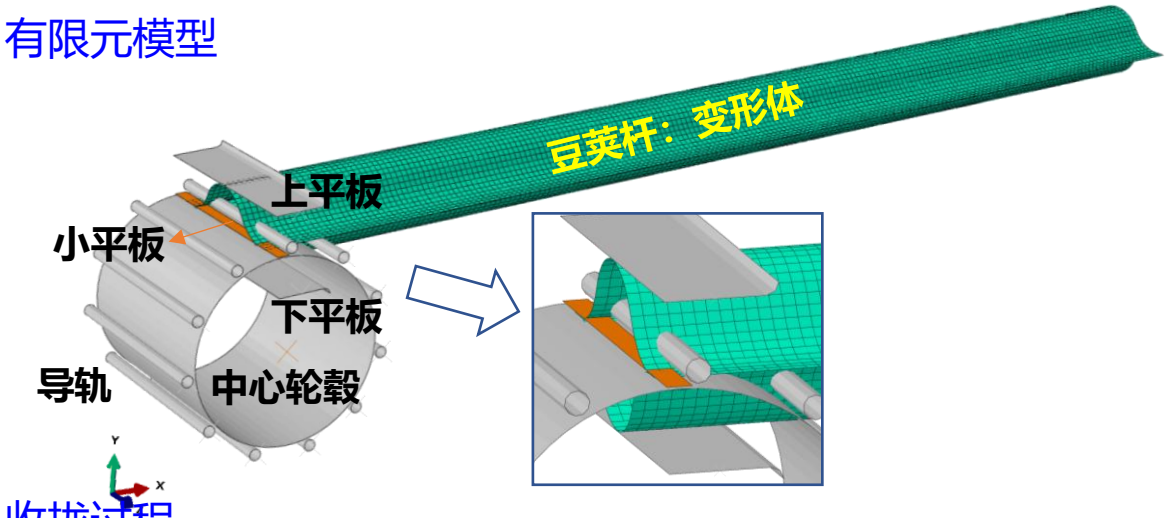
Jia, Q., **An, N.***, et al., 2022. *Composite Structures*, 287, p.115364.

Jia, Q., **An, N.***, et al., 2021. *International Journal of Mechanical Sciences*, *207*, p.106661.

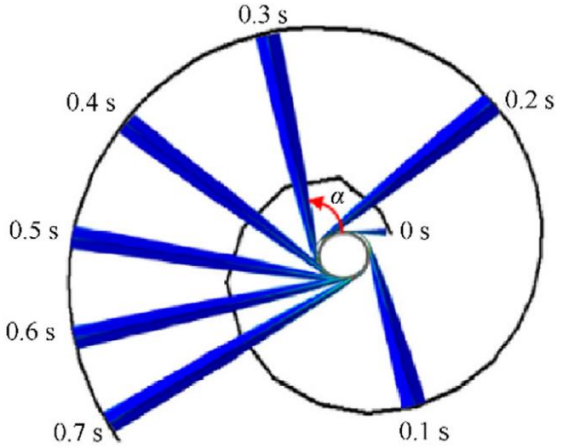
复合材料豆荚杆收拢展开分析

➢ 单根肋收拢展开分析

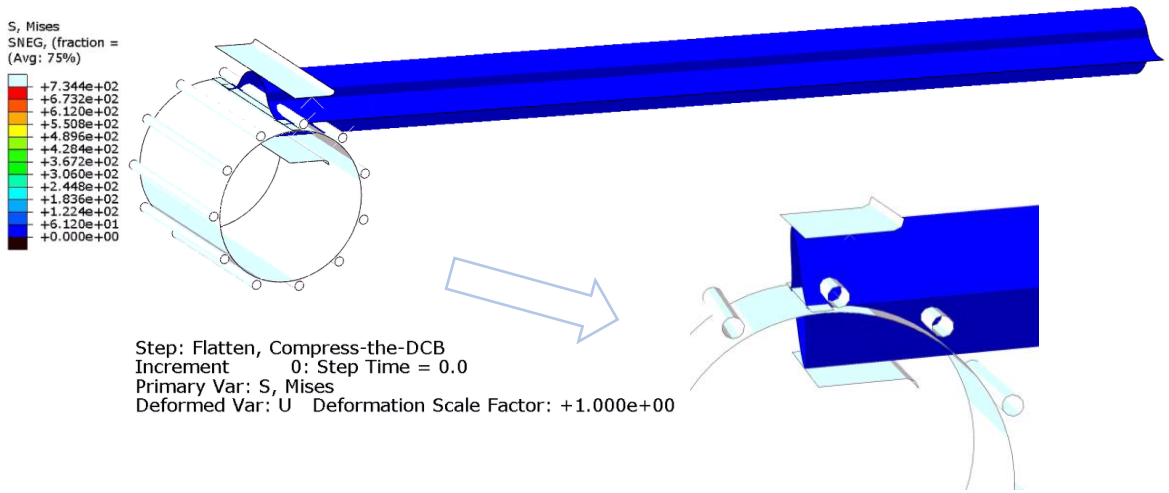
有限元模型



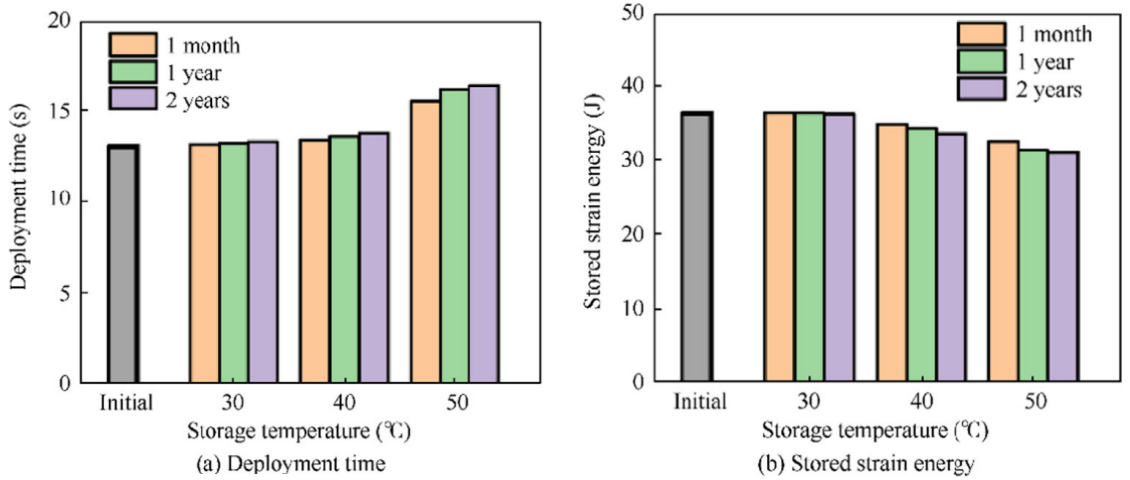
展开过程



收拢过程



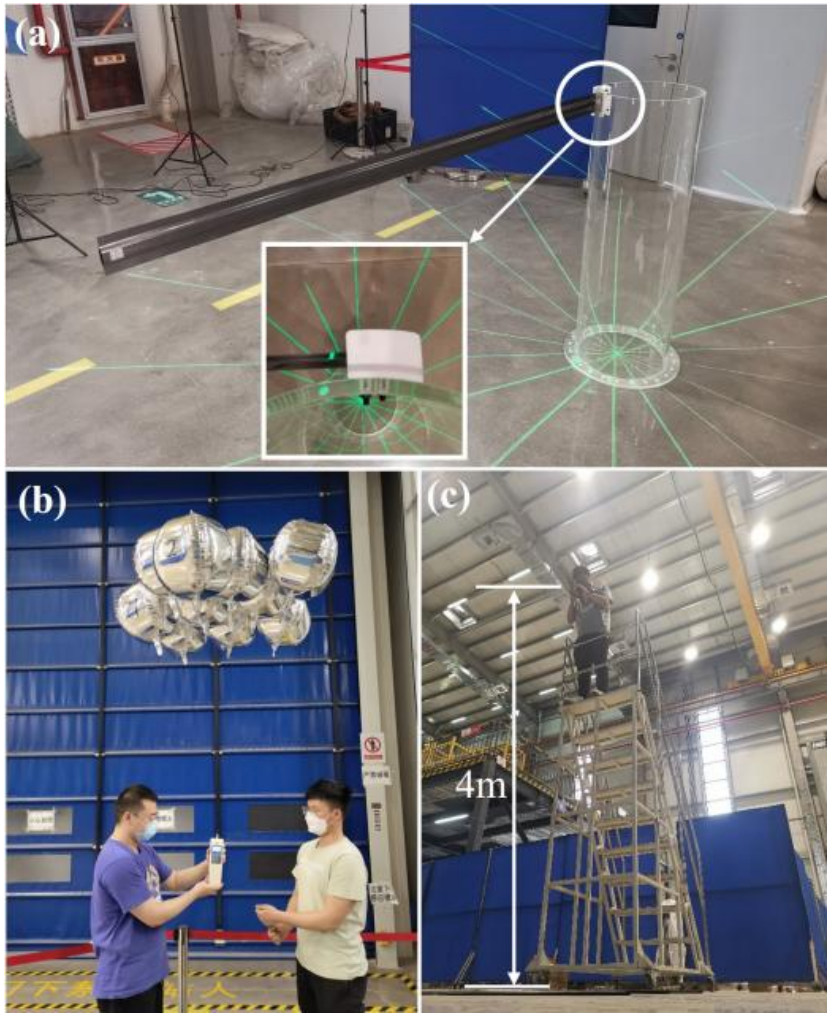
长期收拢的影响

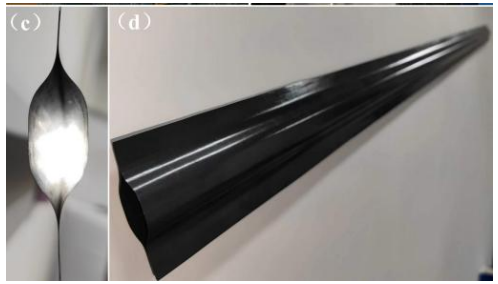


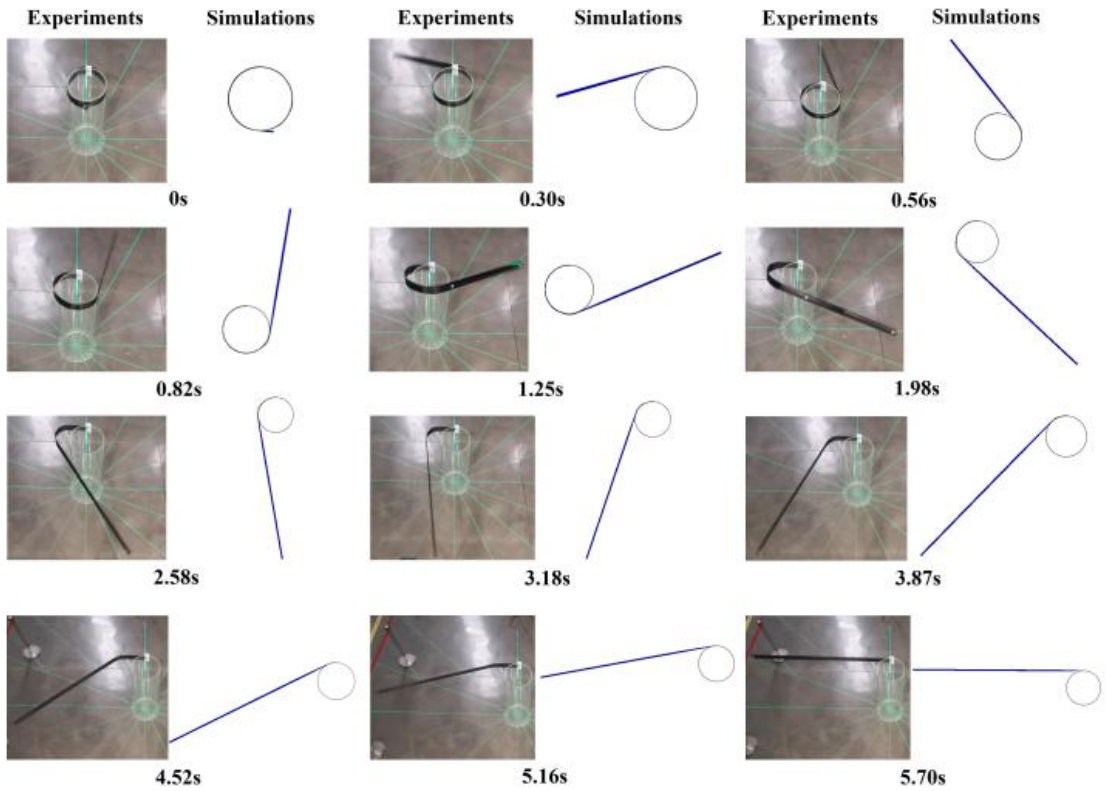
Deng, J., **An, N.***, et al., 2024. *Chinese Journal of Aeronautics*, 37(1), pp.162-172.

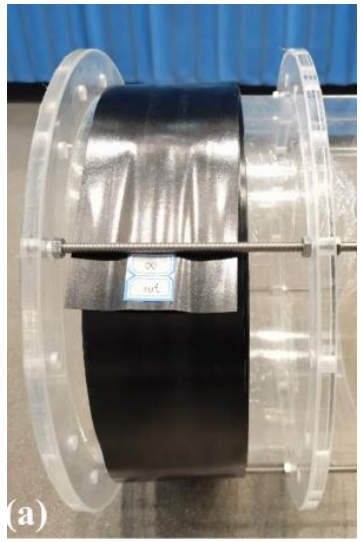
复合材料豆荚杆收拢展开分析

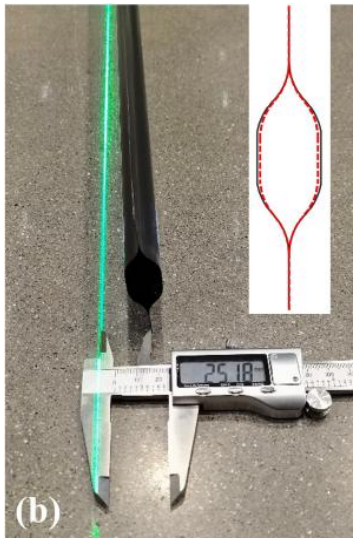
➢ 单根肋展开动力学试验





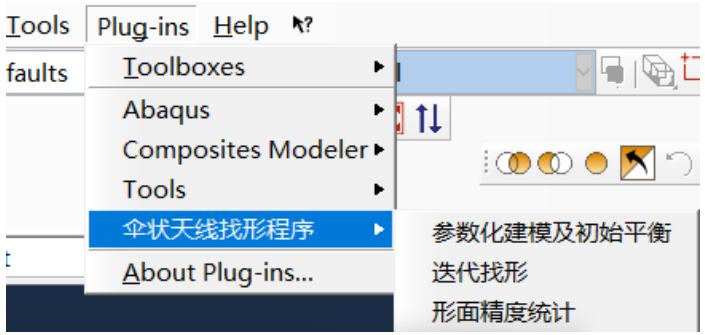


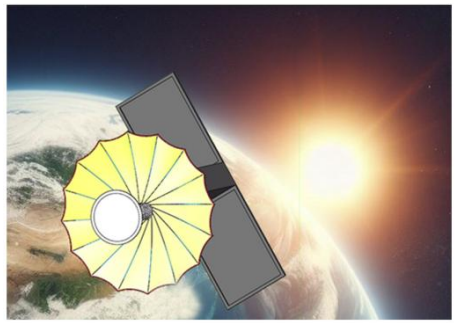


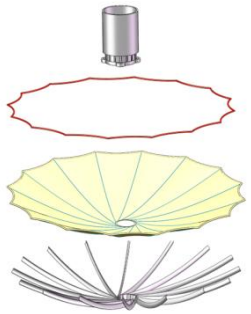


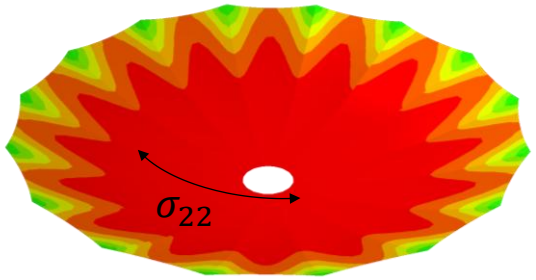
Guo, R.#, Jin, X.#, Jia, Q., Ma, X., **An, N.*** and Zhou, J., 2023. Acta Astronautica, 213, pp.567-577.

伞天线找形分析方法与软件定制

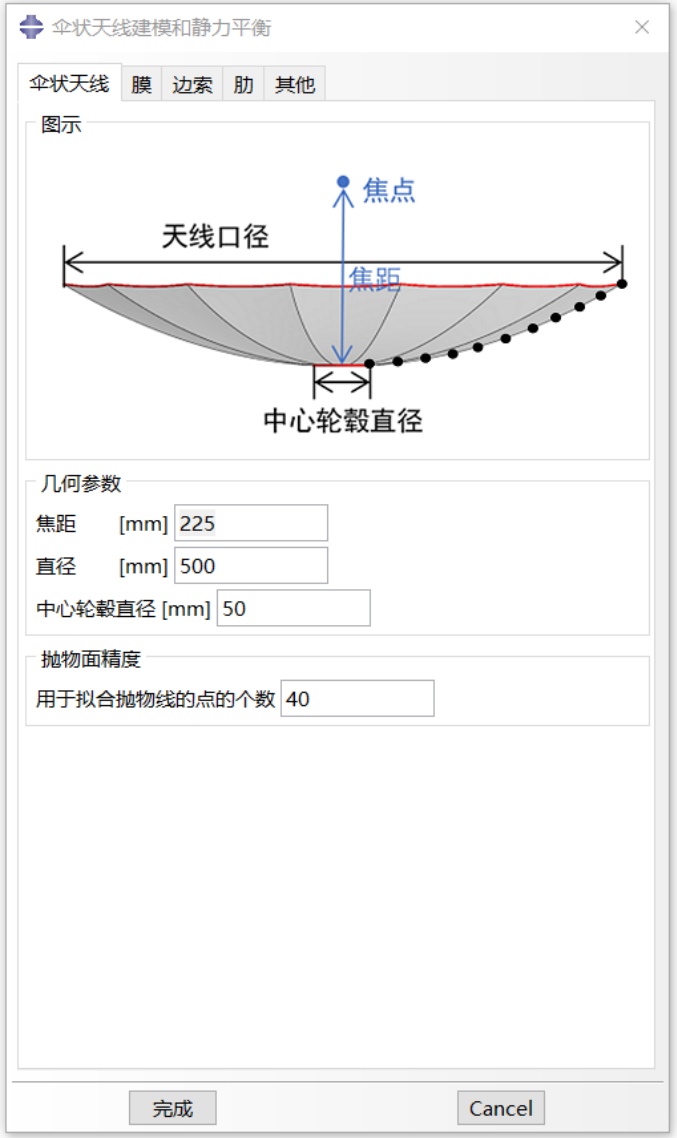


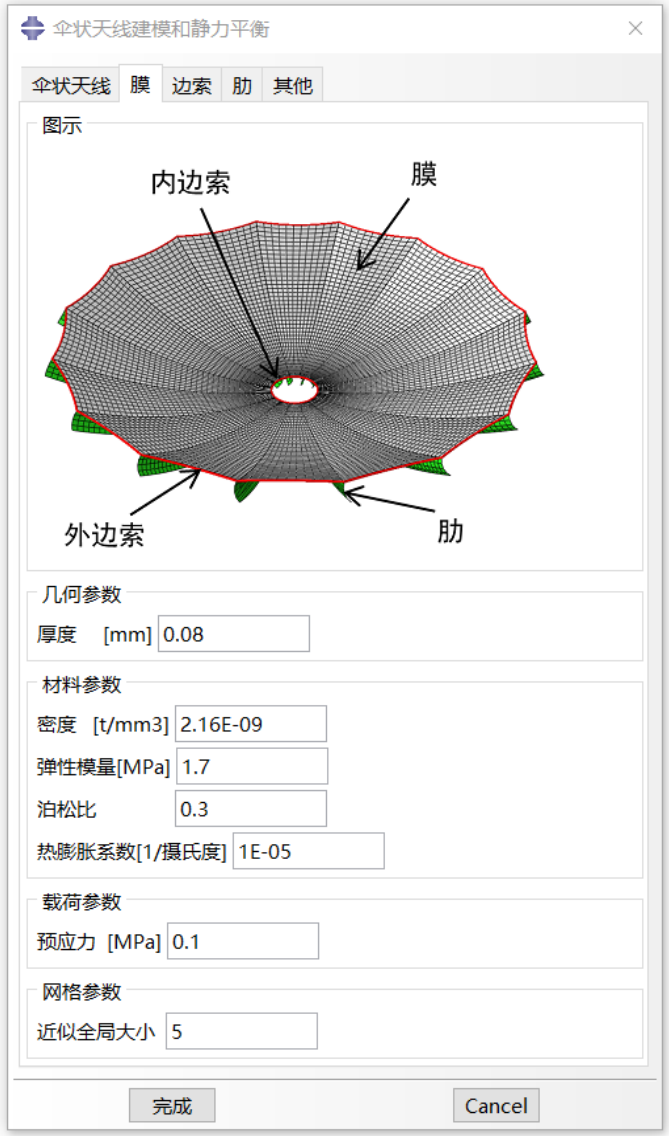






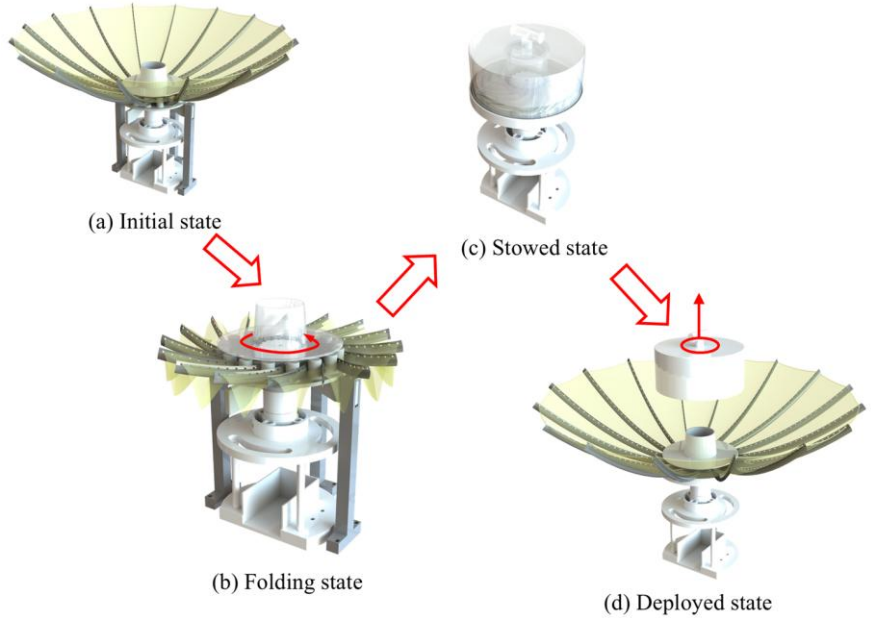
RMSE = 1.77 mm

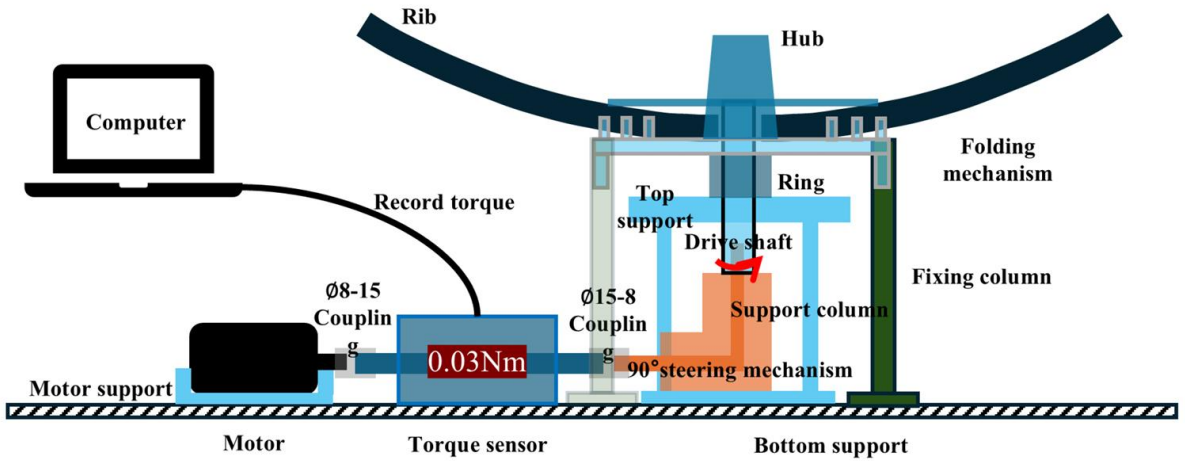


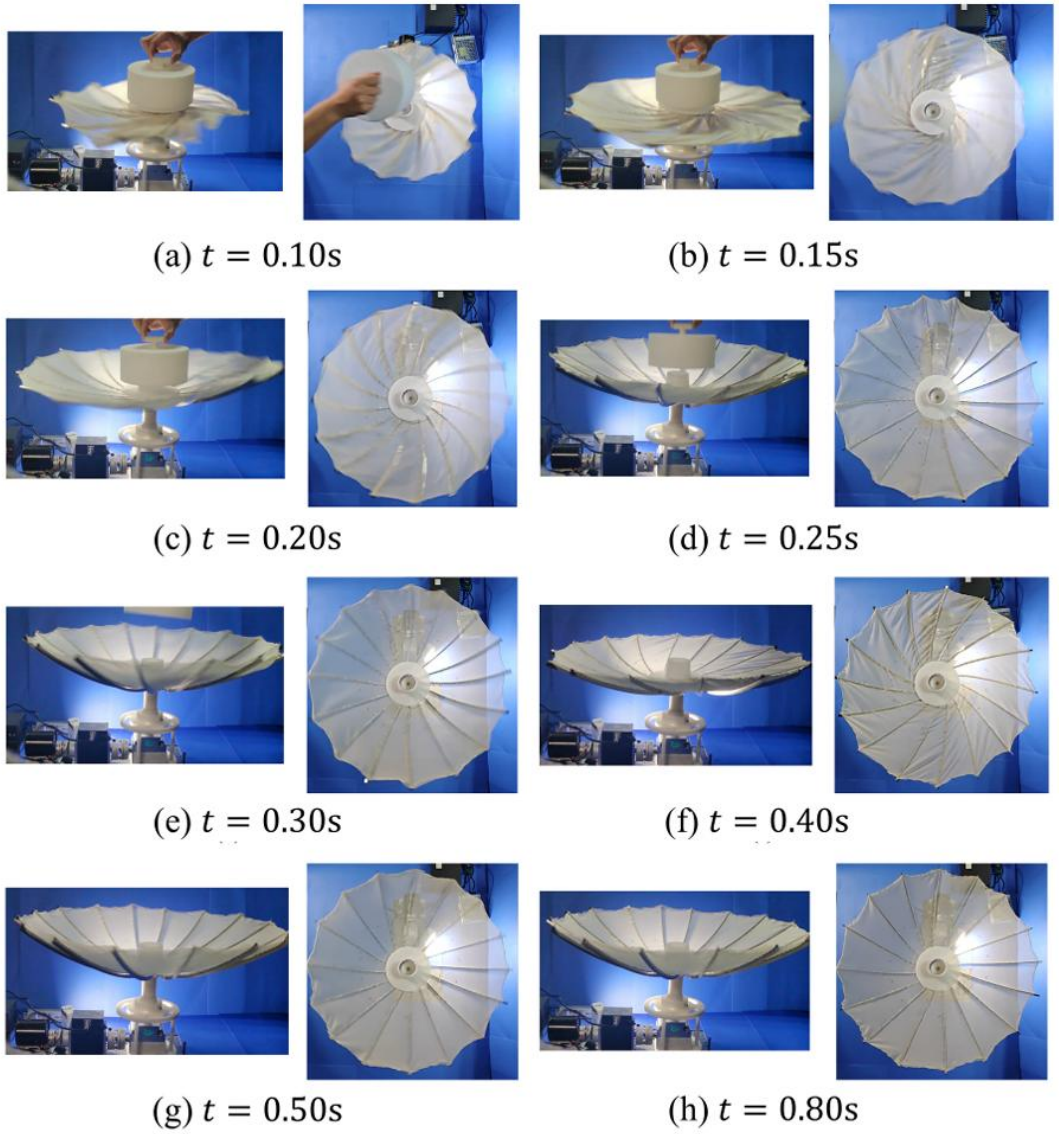


Zhu, S., ..., and **An, N.* (2024)**. *Advances in Engineering Software*, 198, 103789.

缠绕肋天线结构设计与收拢展开

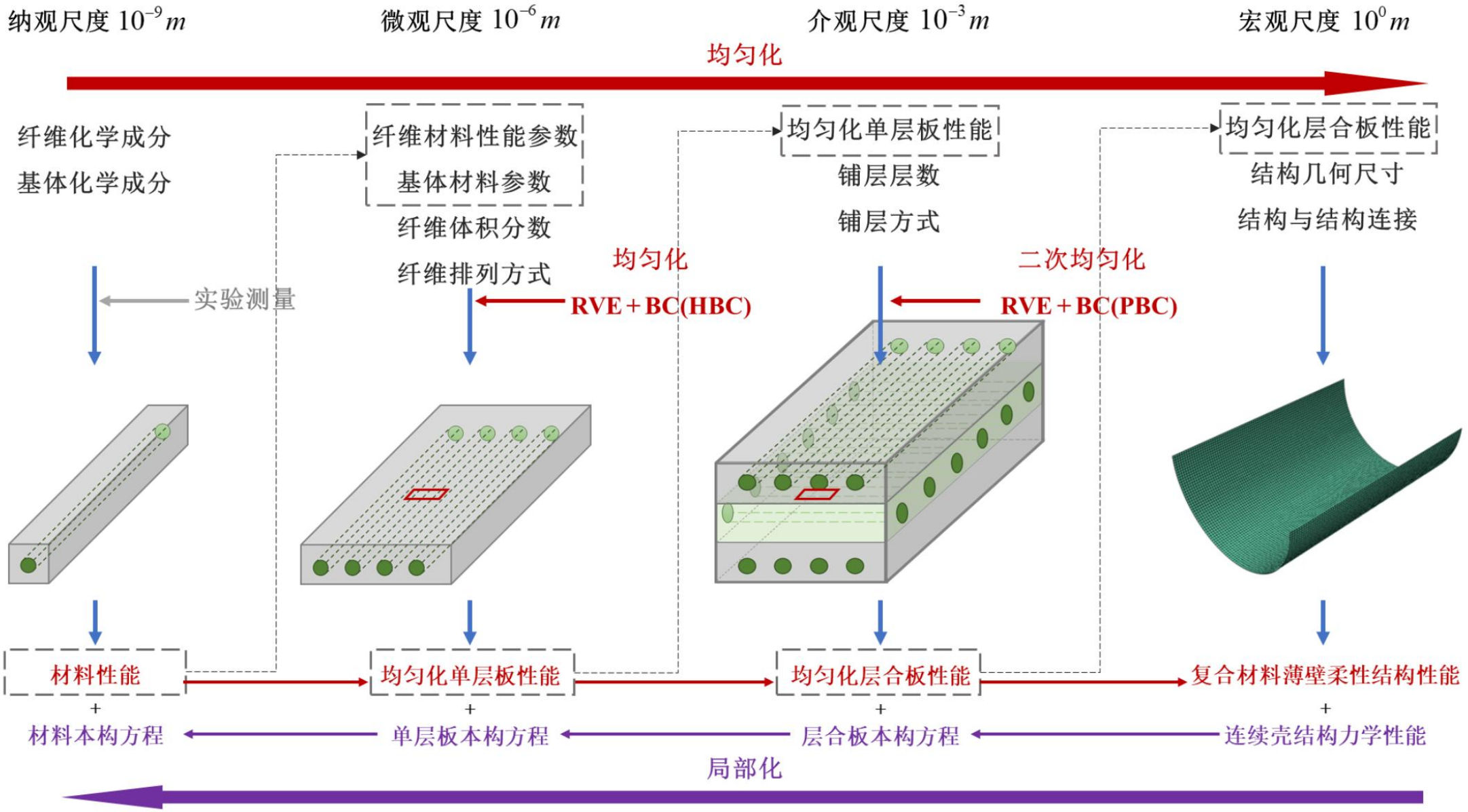






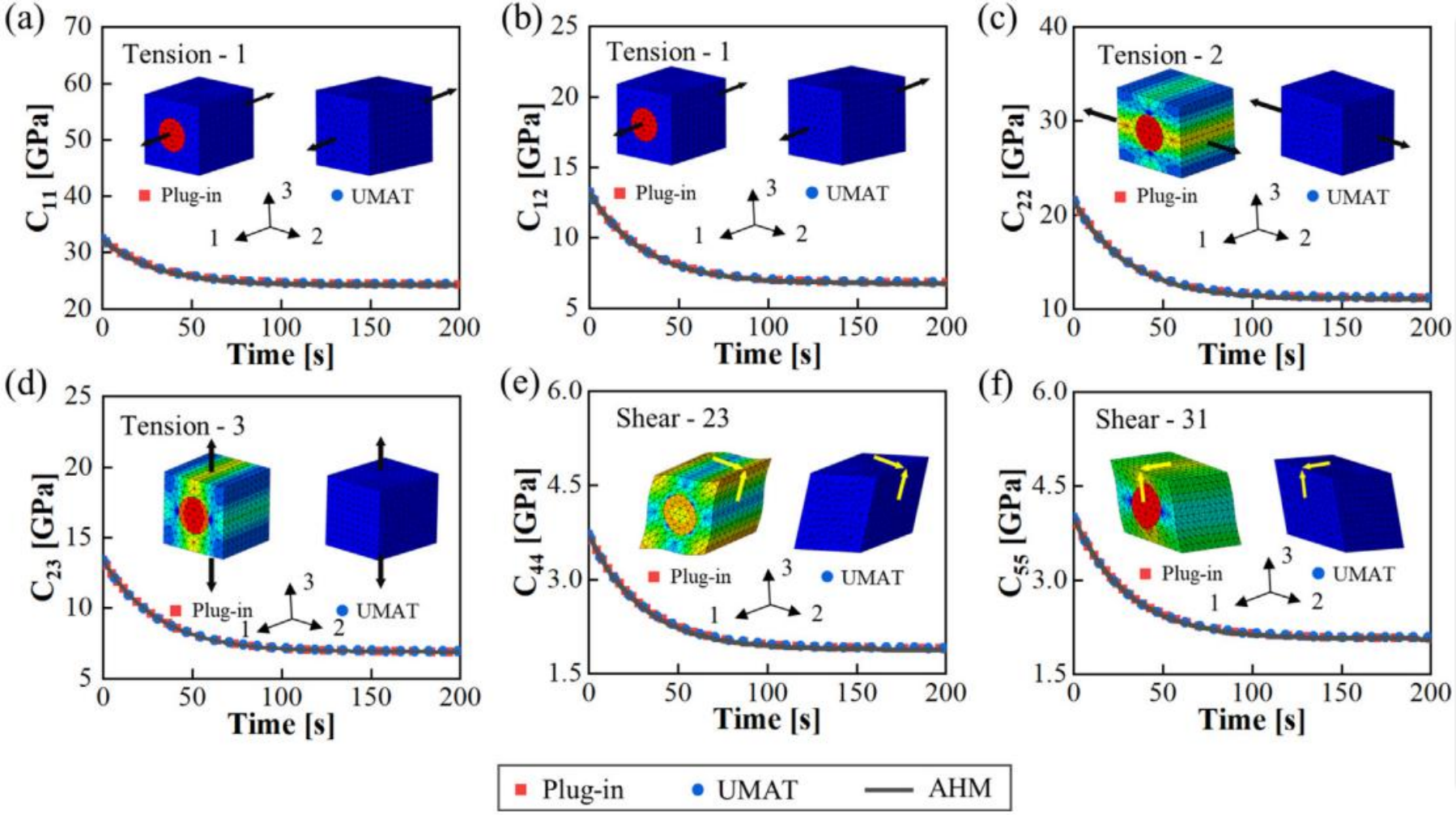
Zhu, S.#, Guo, R.#, Liu, H., ..., and **An, N.* (2025)**. *Submitted.*

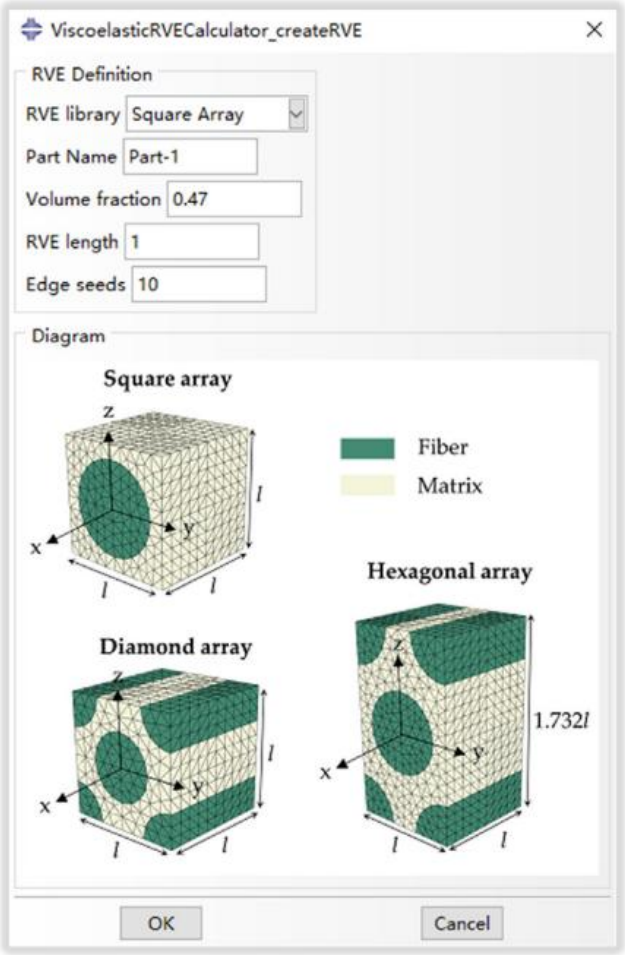
复合材料多尺度力学分析



复合材料多尺度力学分析

➢ 复合材料微观力学模型（计算力学软件开发）

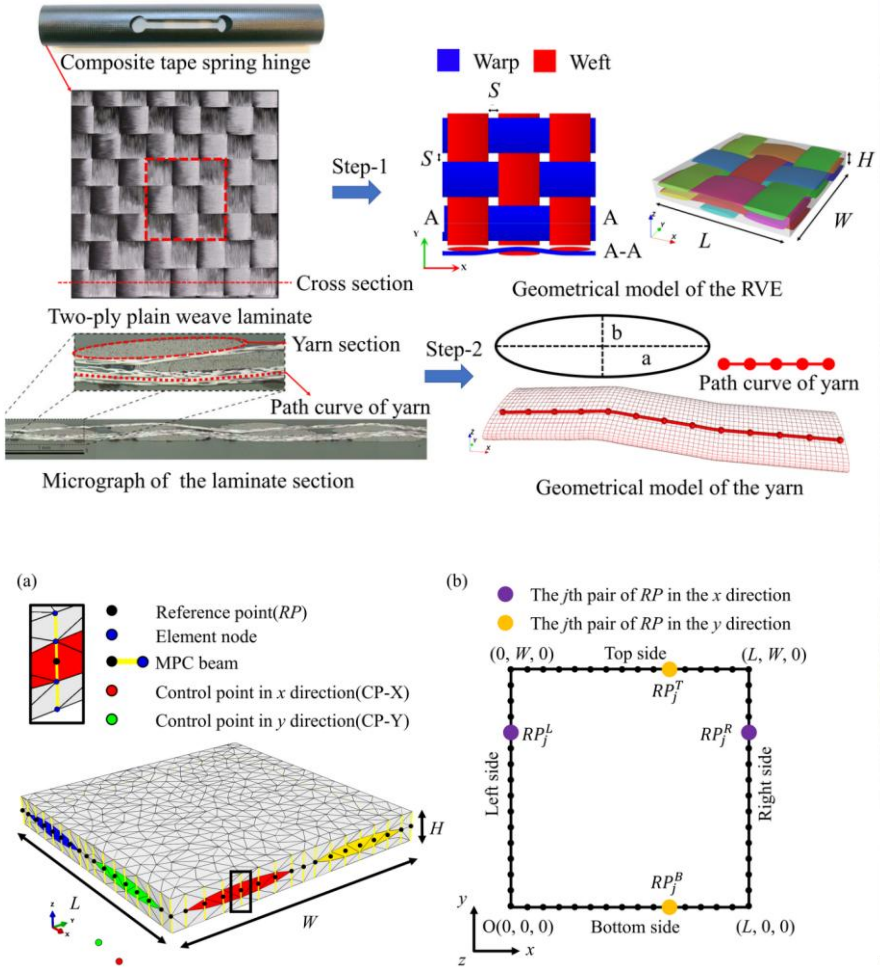


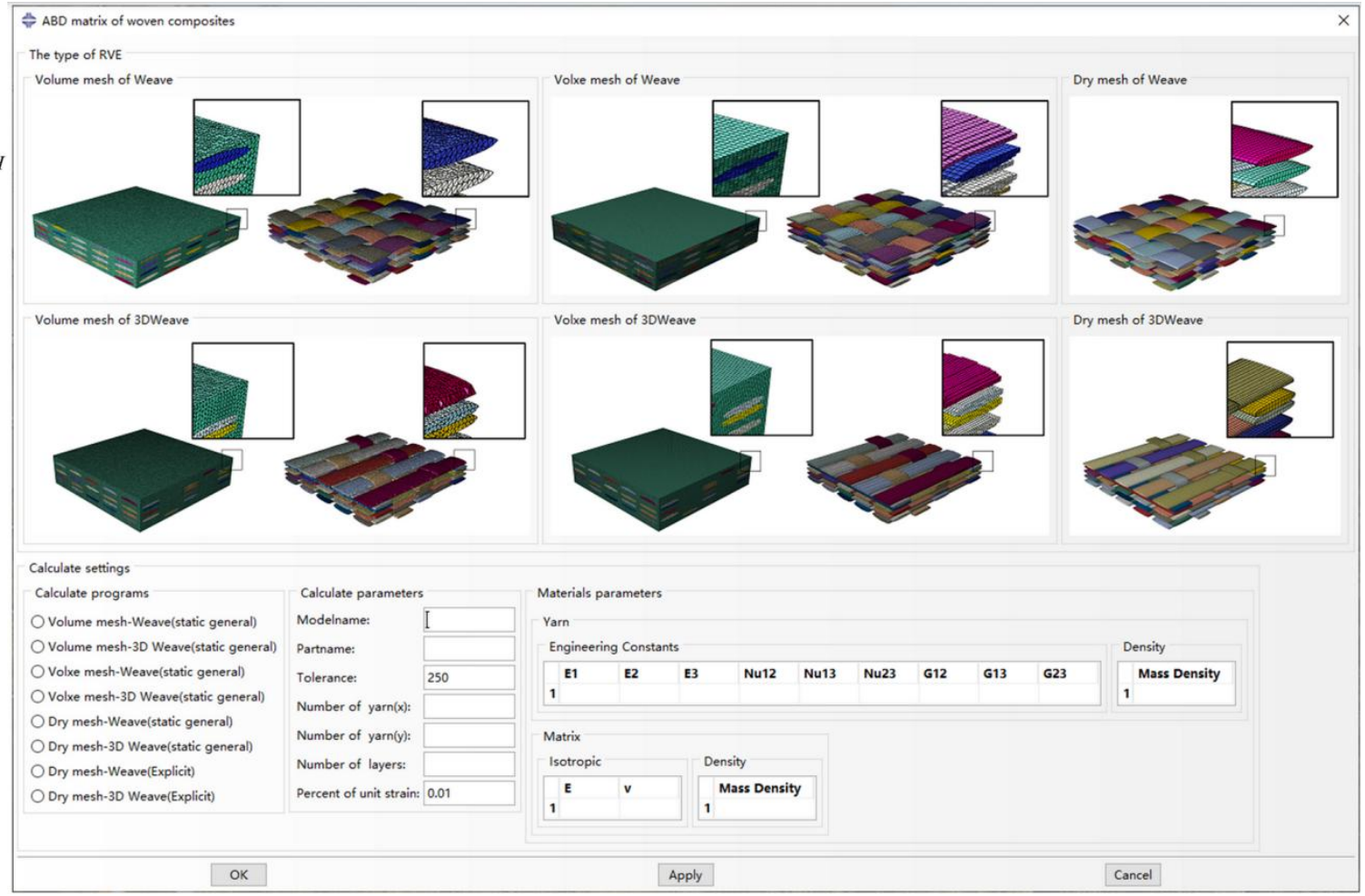


An, N.*, et al. 2022. *Materials & Design*, *219*, p.110754.

复合材料多尺度力学分析

➢ 编织复合材料力学性能分析（计算力学软件开发）

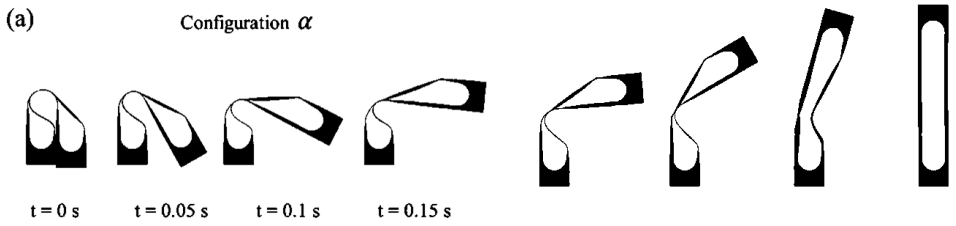


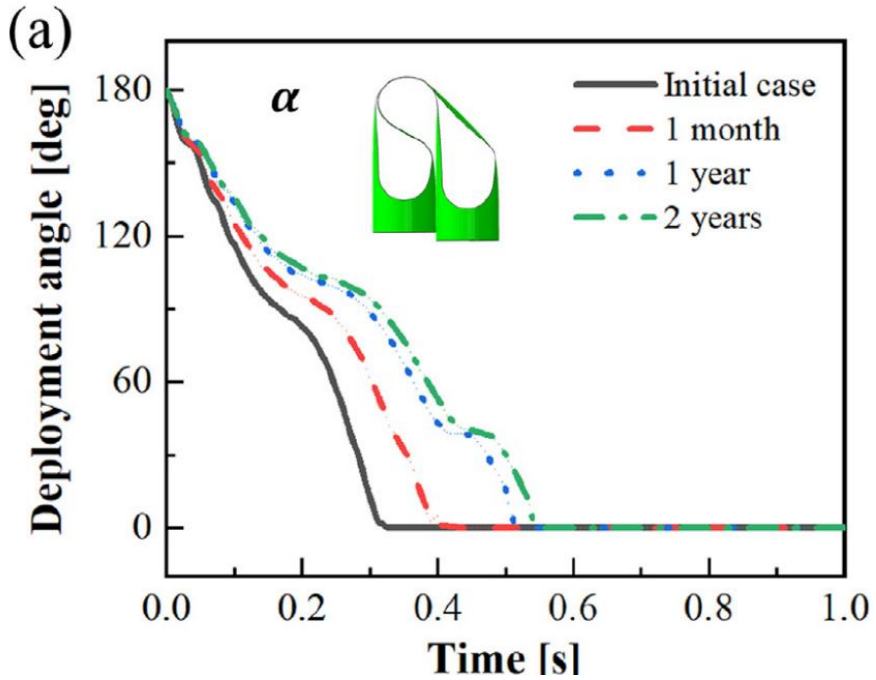


Jin, H., **An, N.***, et al., 2024. *Composite Structures*, 337, p.118031.

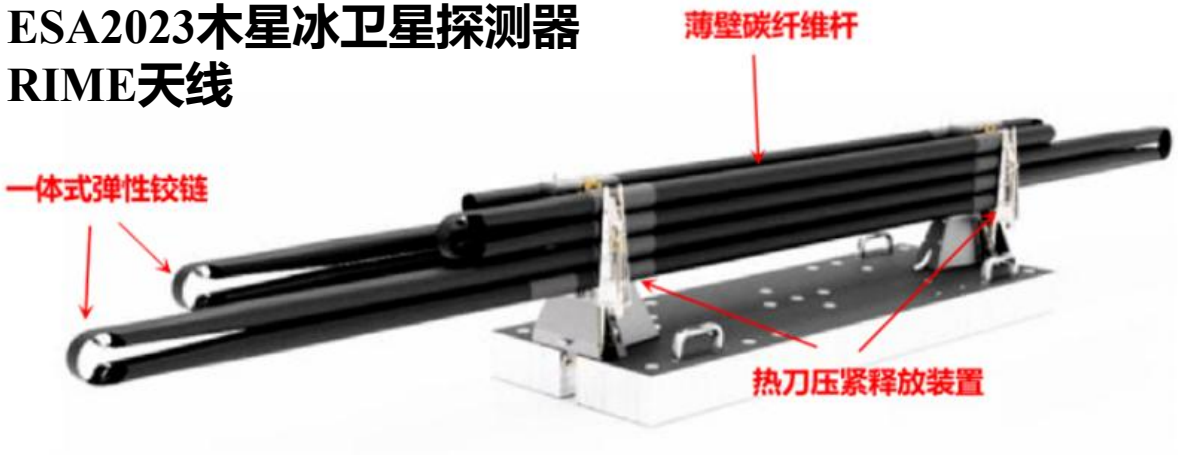
复合材料带簧铰链结构

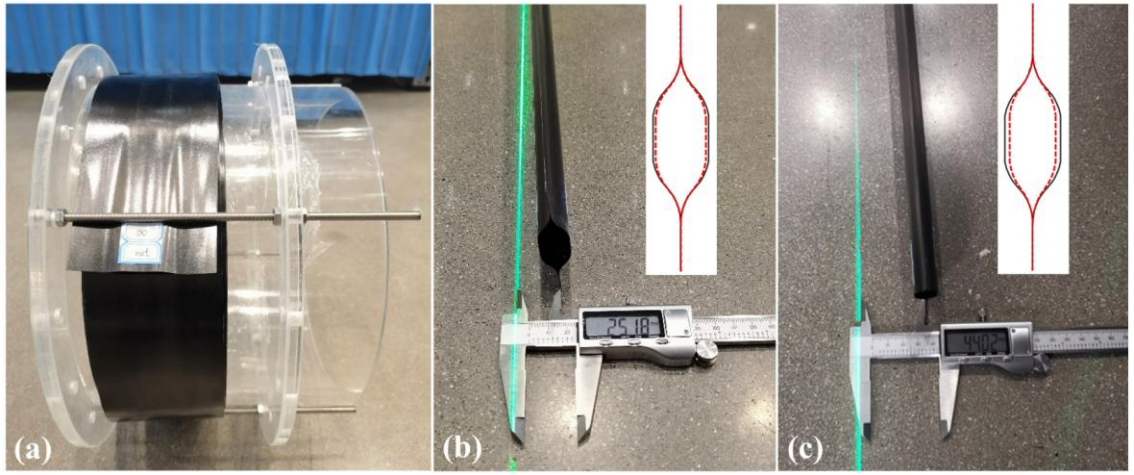
- **长期折叠储存后材料发生应力松弛，导致展开事故。**





ESA2023木星冰卫星探测器
RIME天线

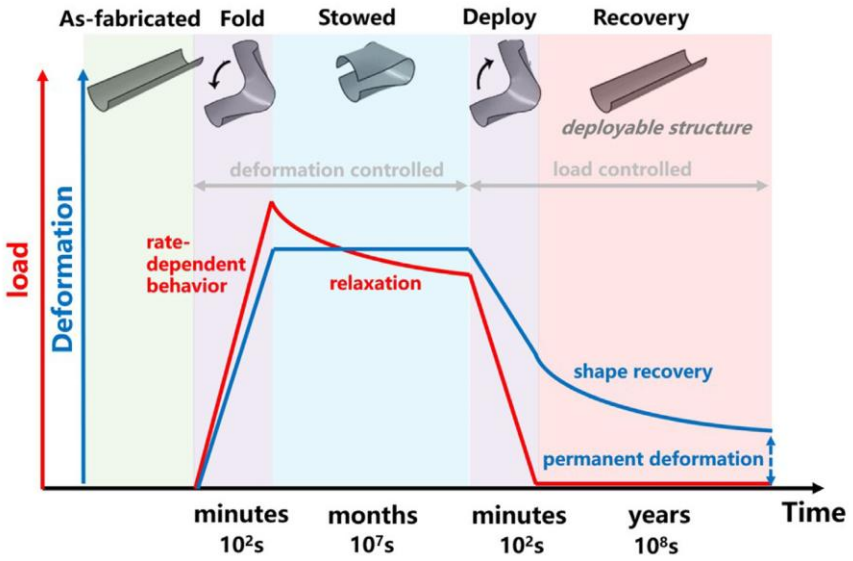


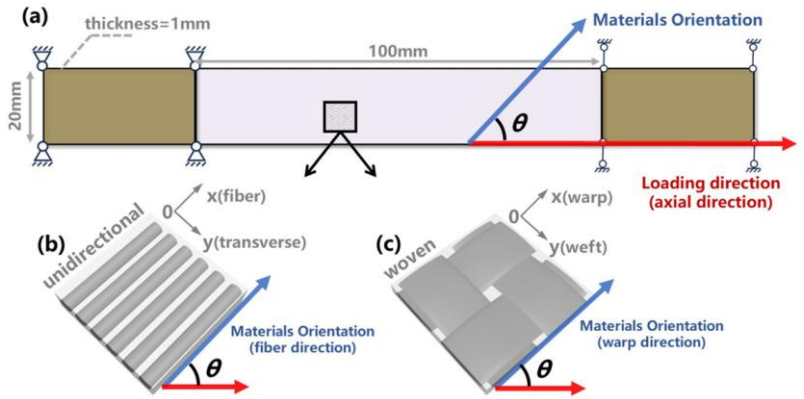


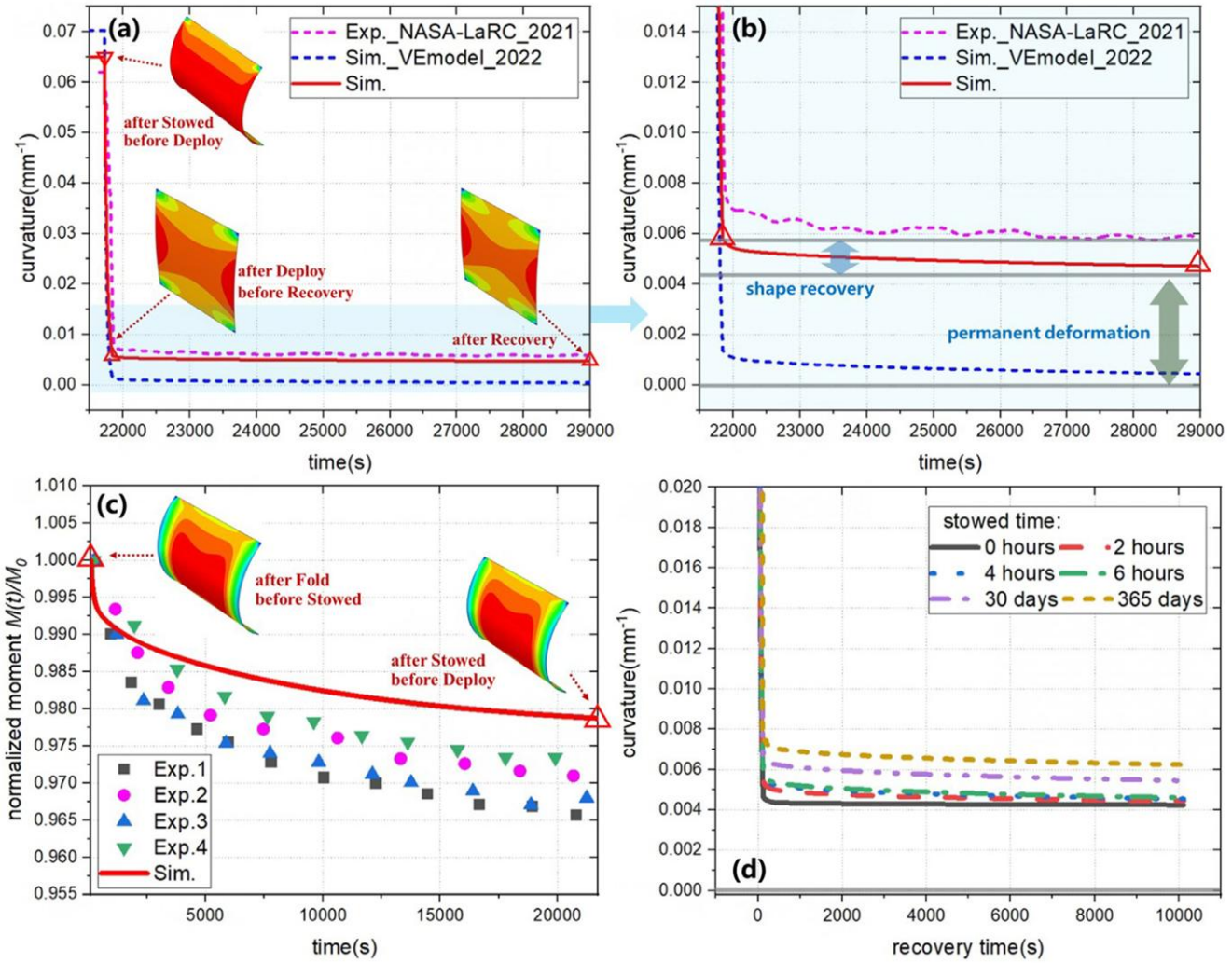
An, N.*, et al. 2022. *Materials & Design*, *219*, p.110754.

复合材料多尺度力学分析

➢ 各向异性粘弹-粘塑性力学







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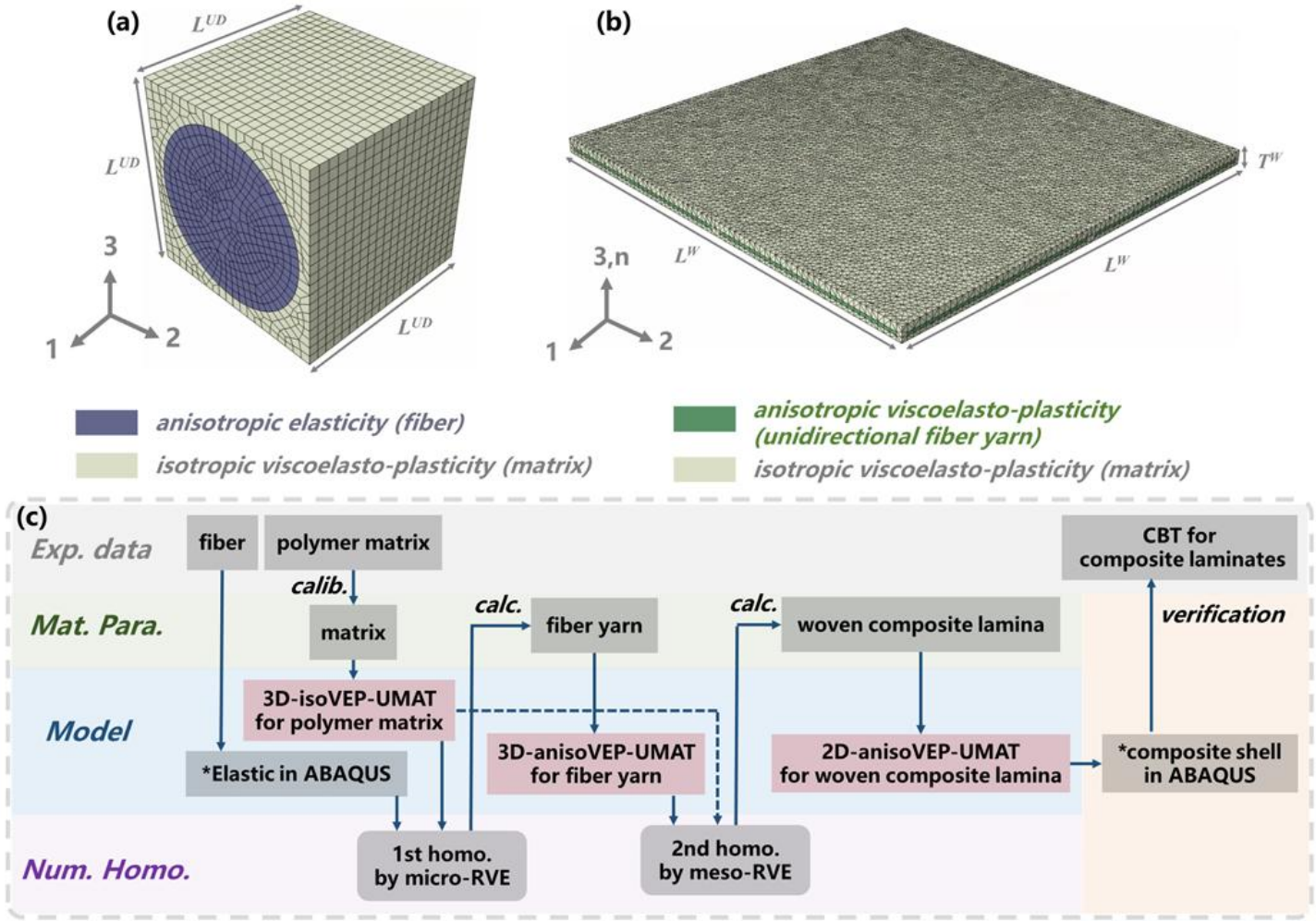
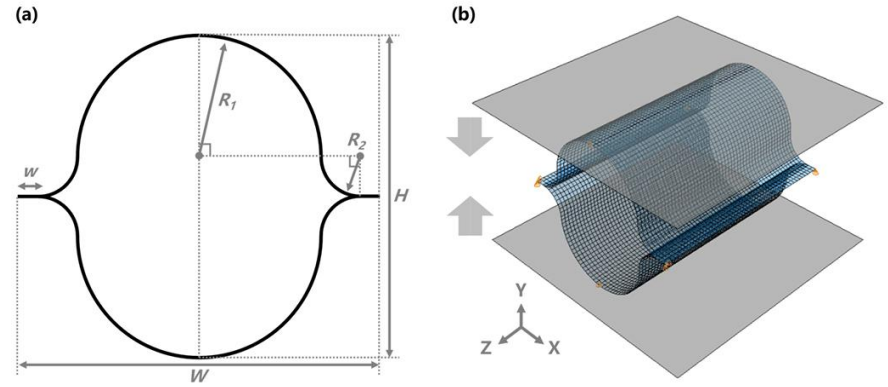
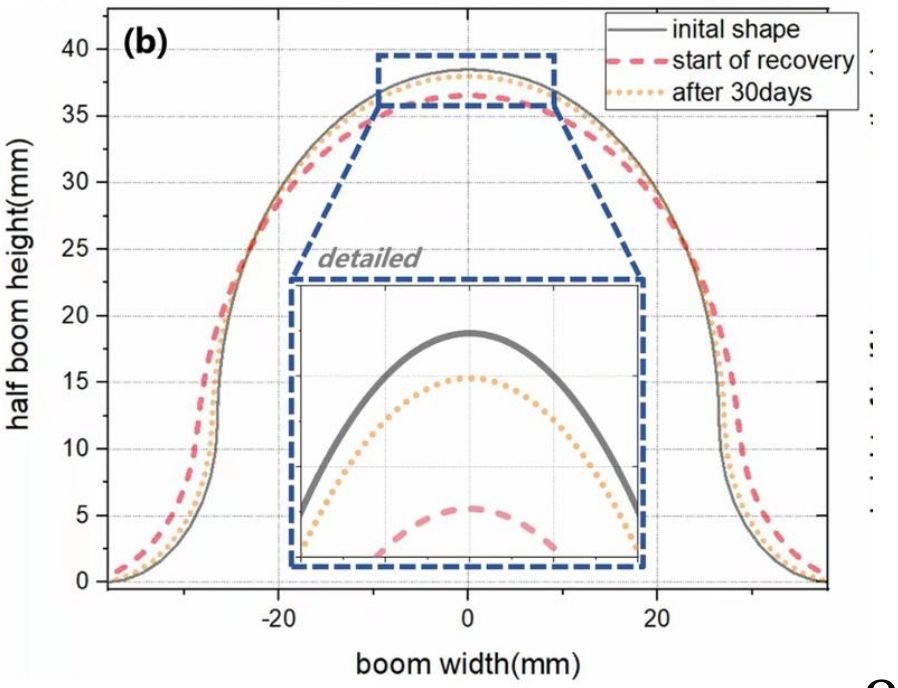
复合材料多尺度力学分析

➢ 各向异性粘弹-粘塑性力学







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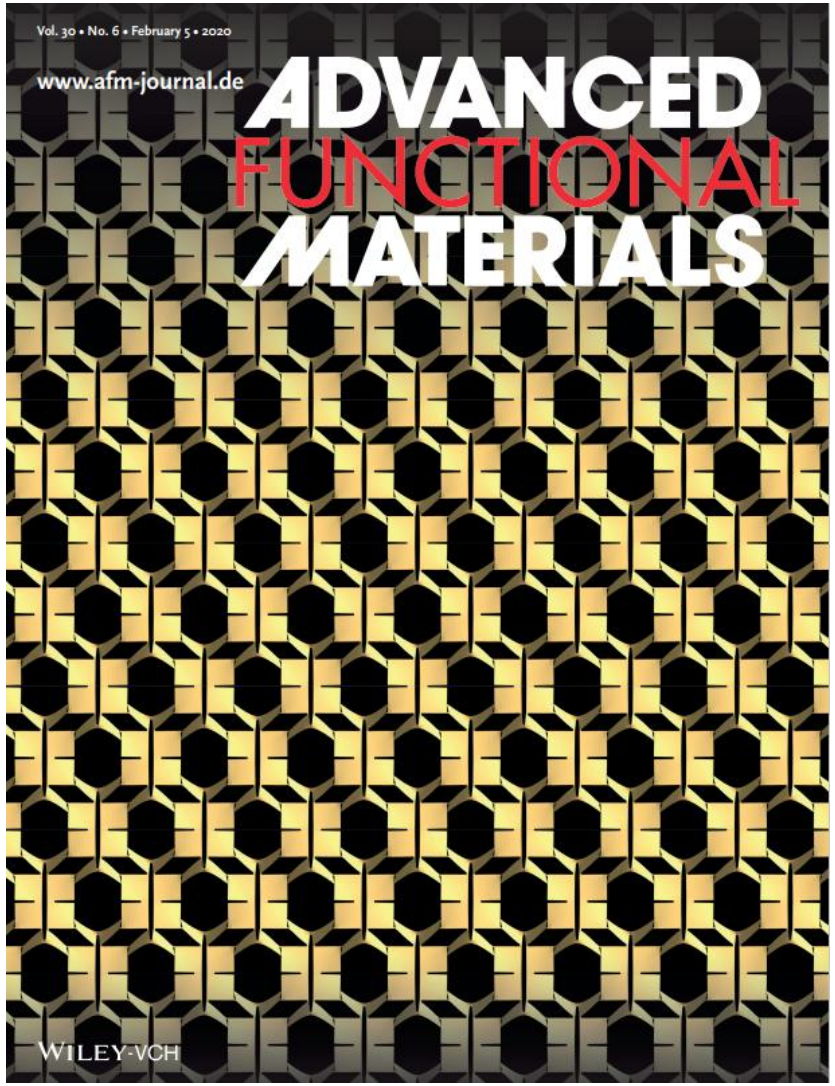
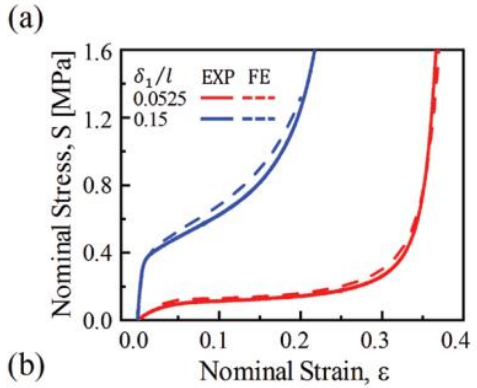
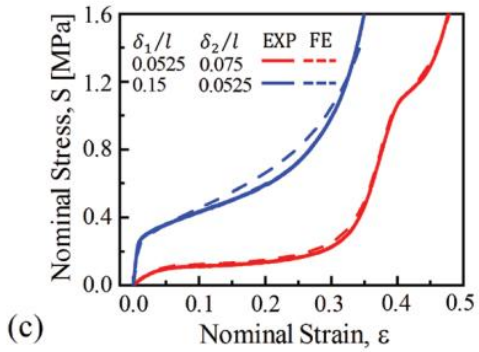
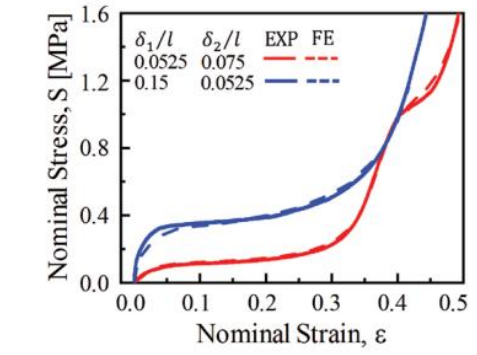
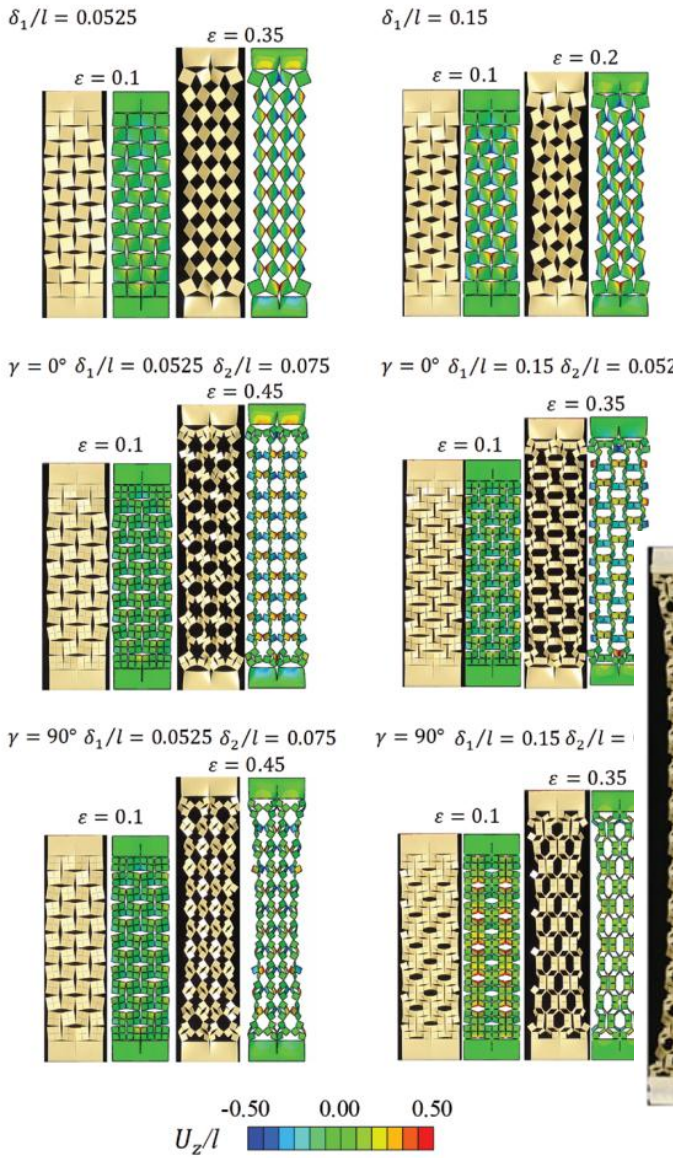
剪纸力学超材料

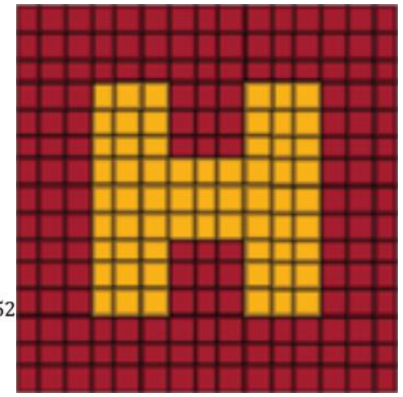


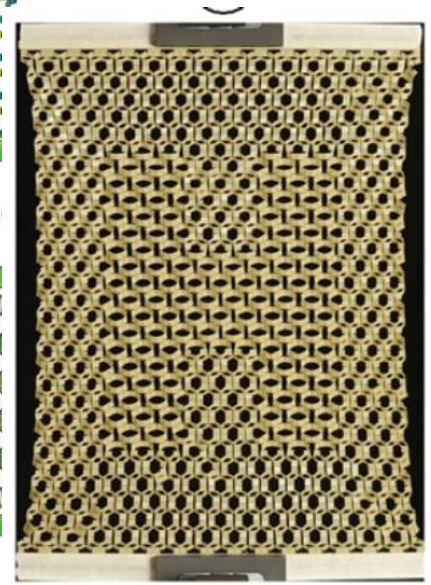












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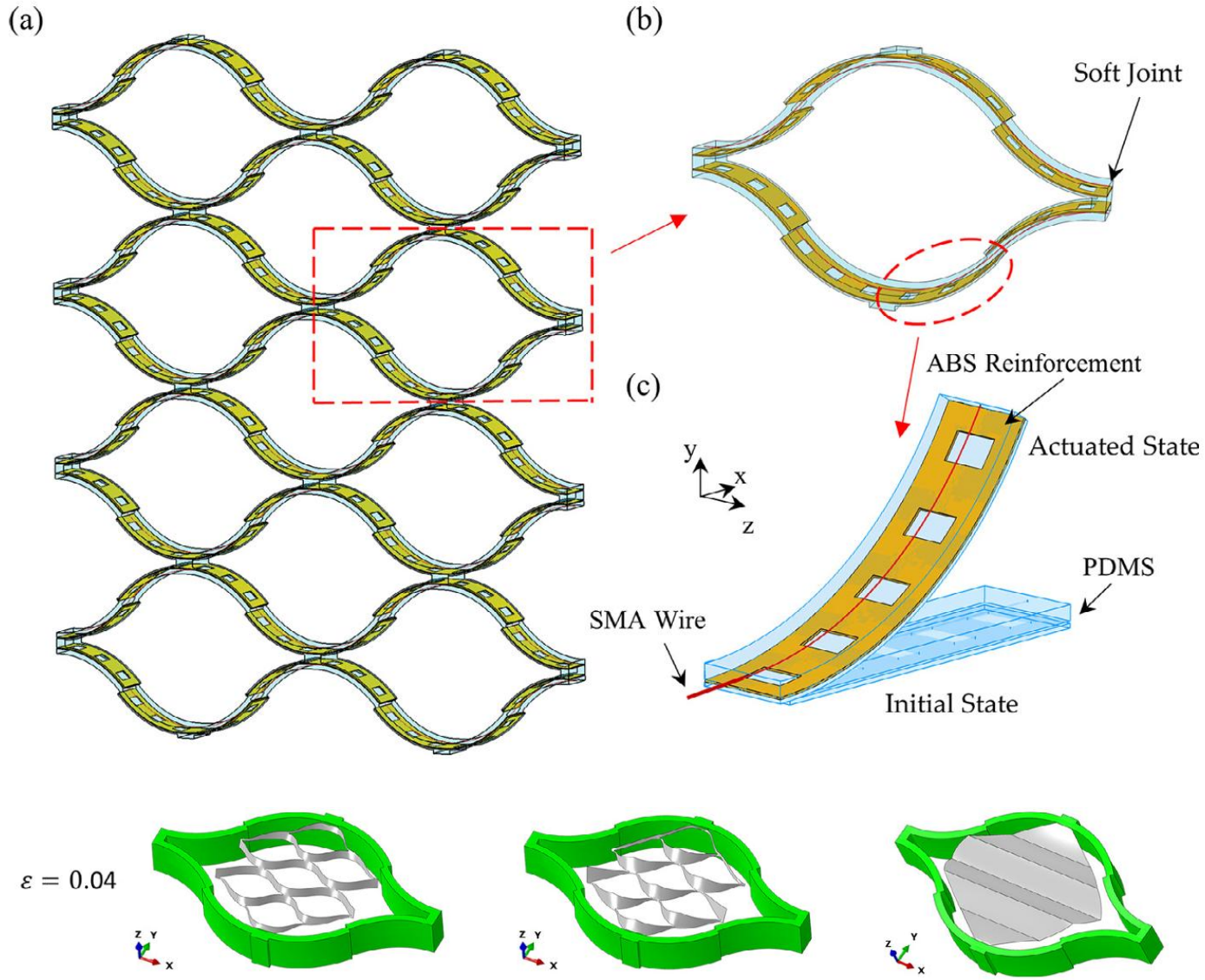
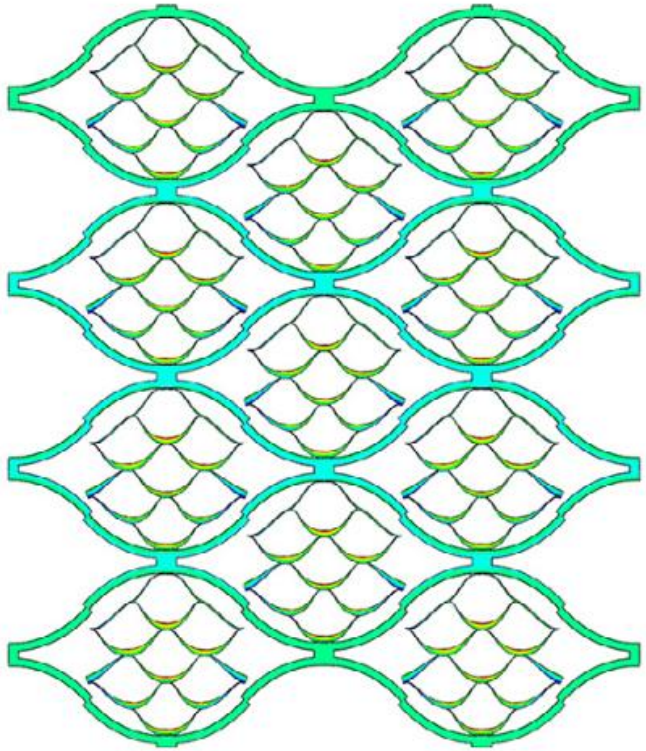
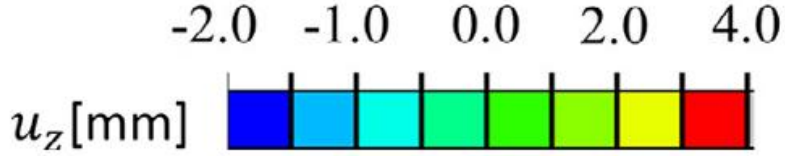
剪纸/折纸力学超材料







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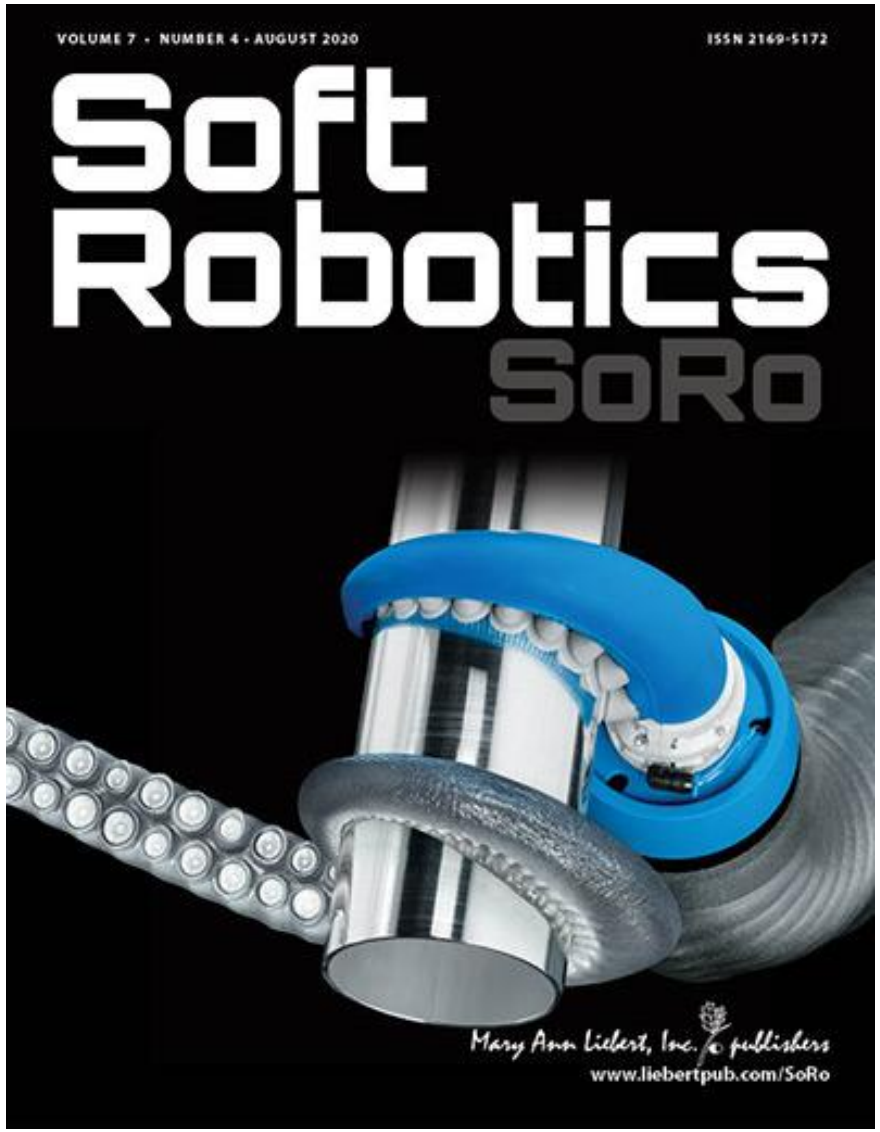
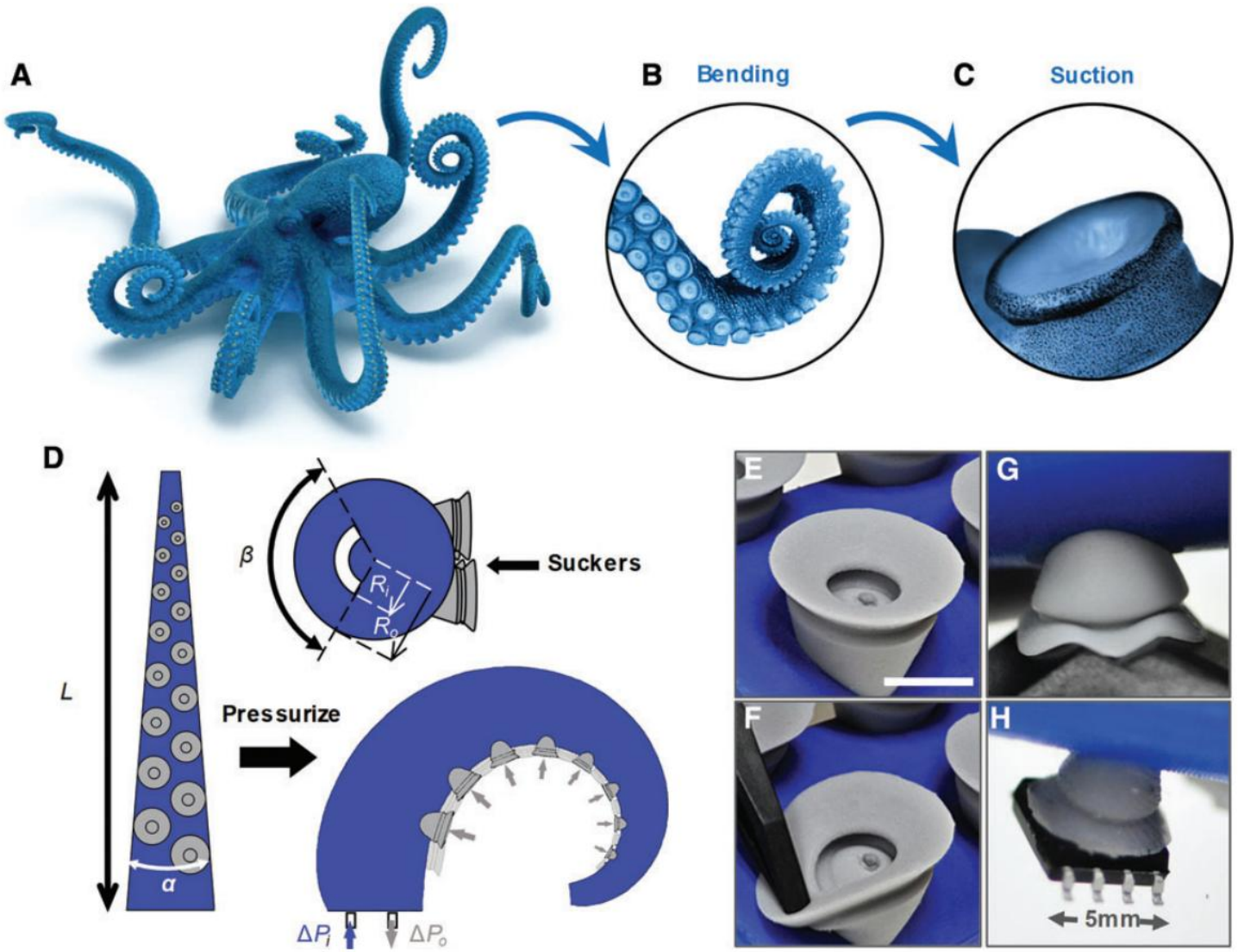
软体机器人





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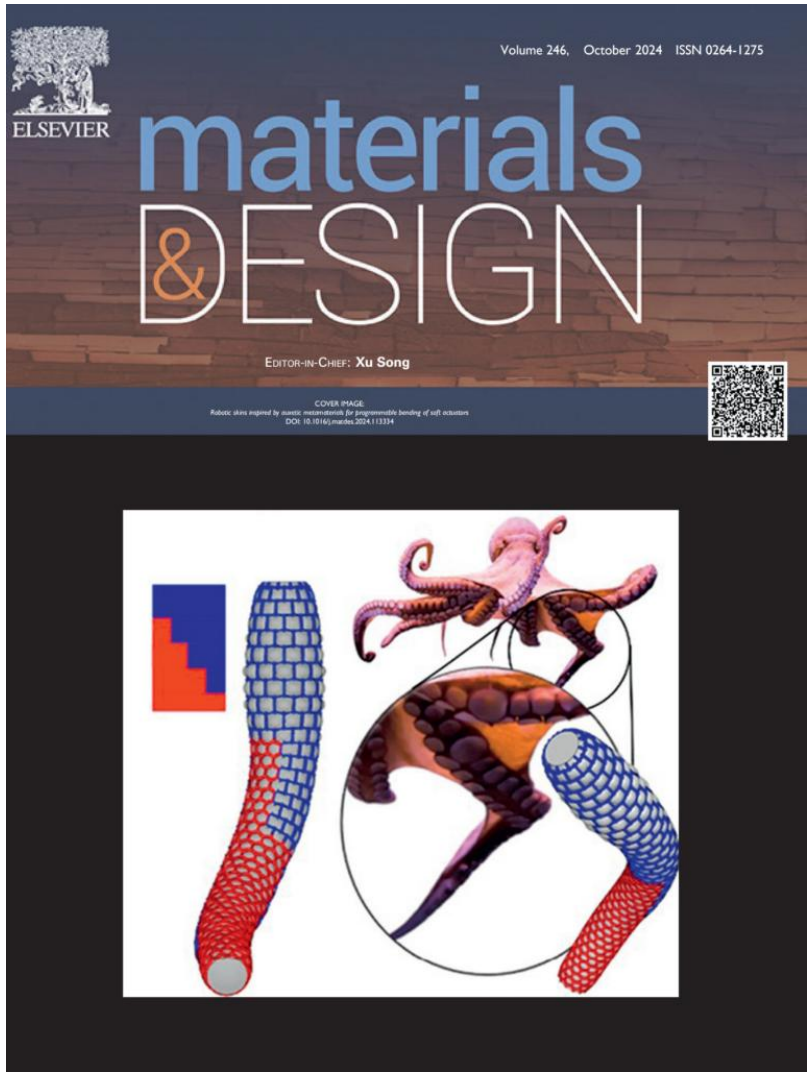
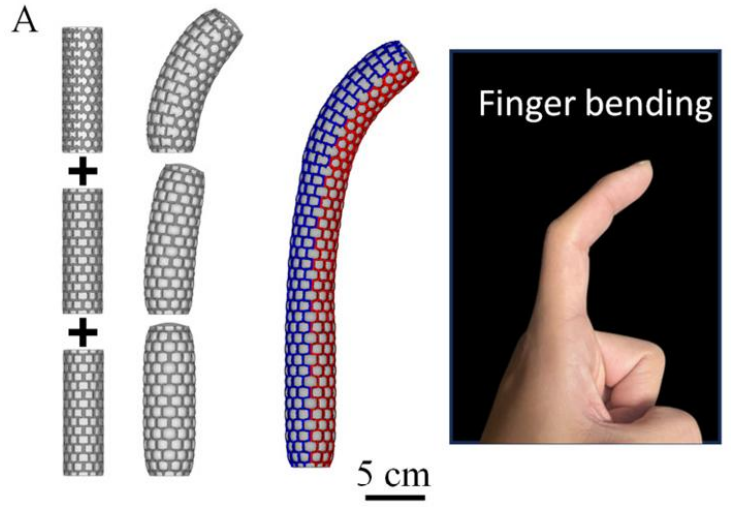
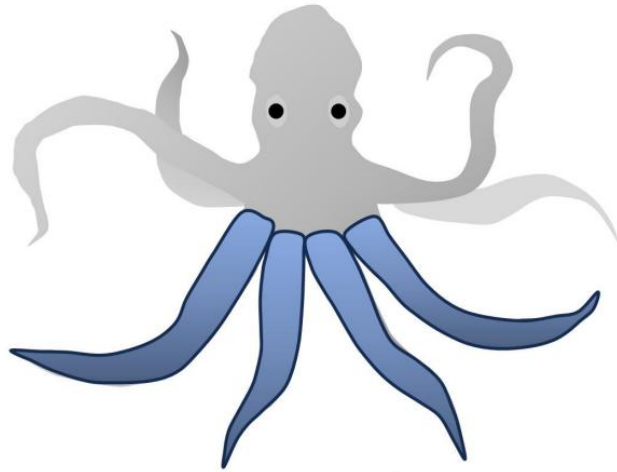
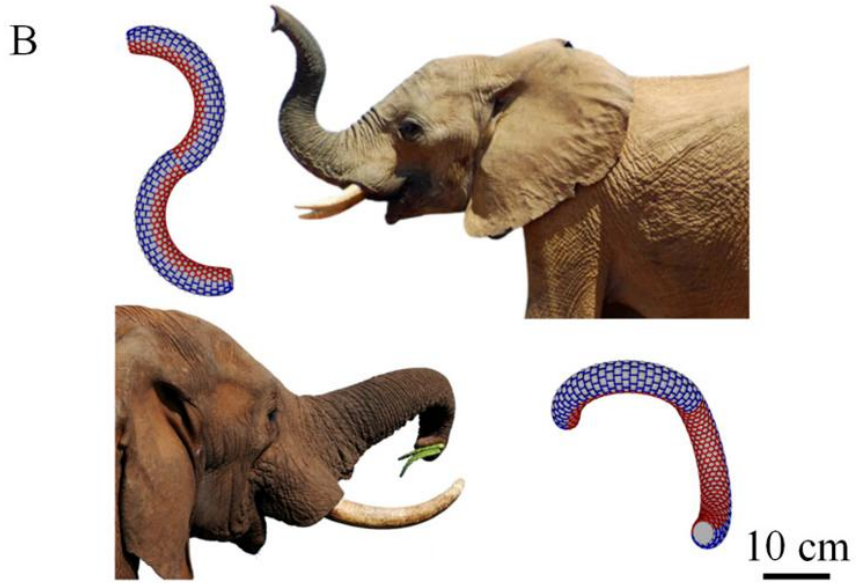
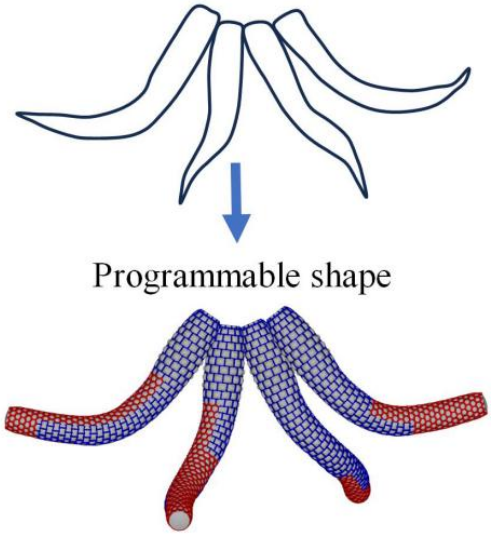
软体机器人











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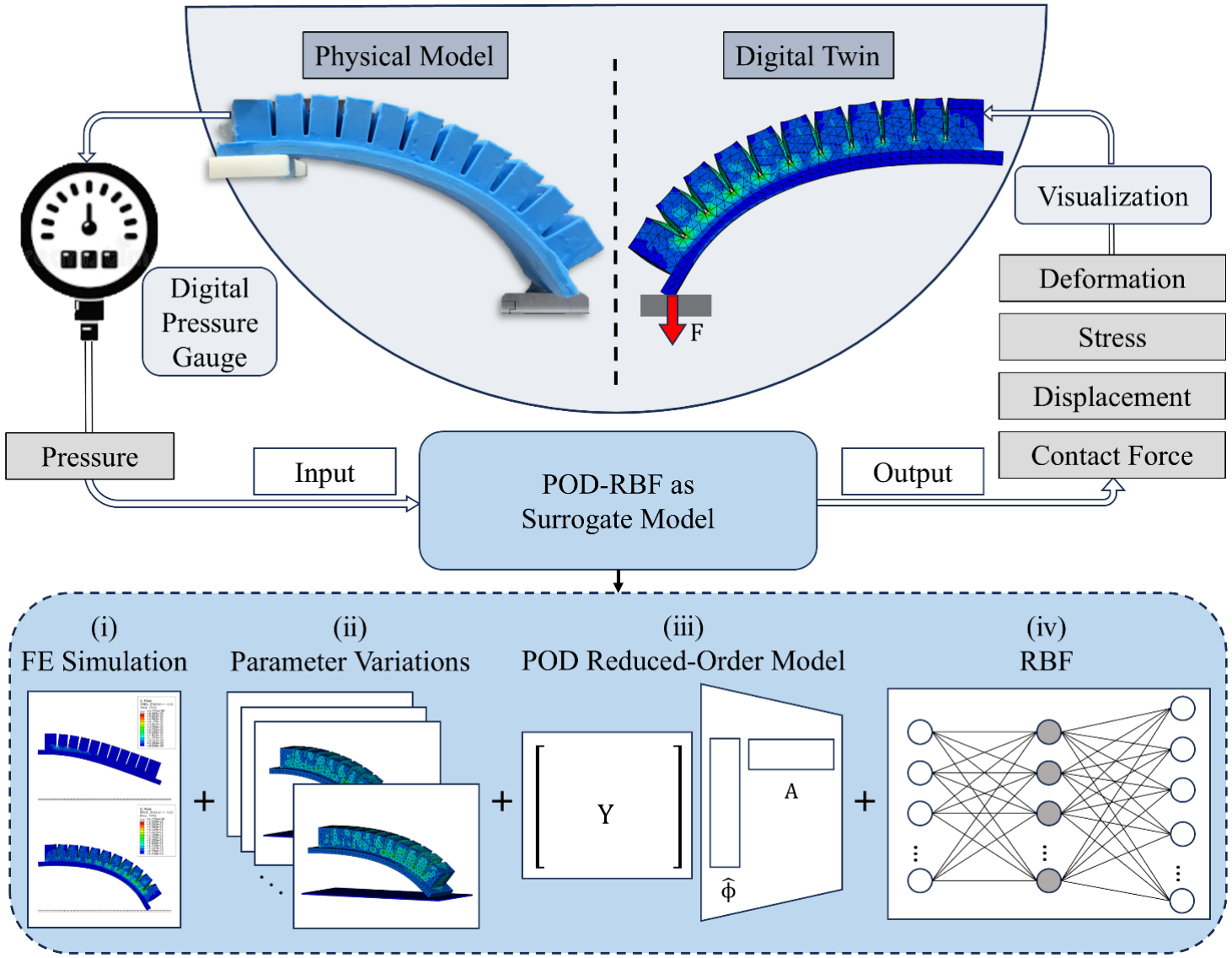

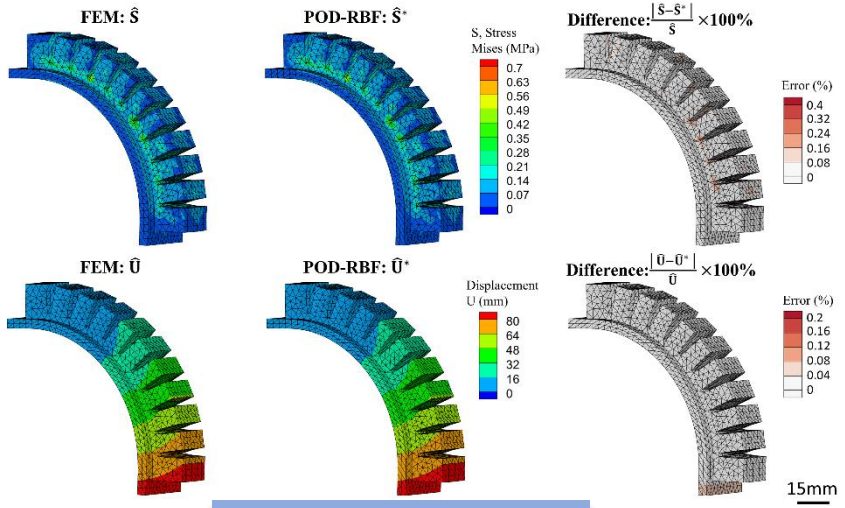

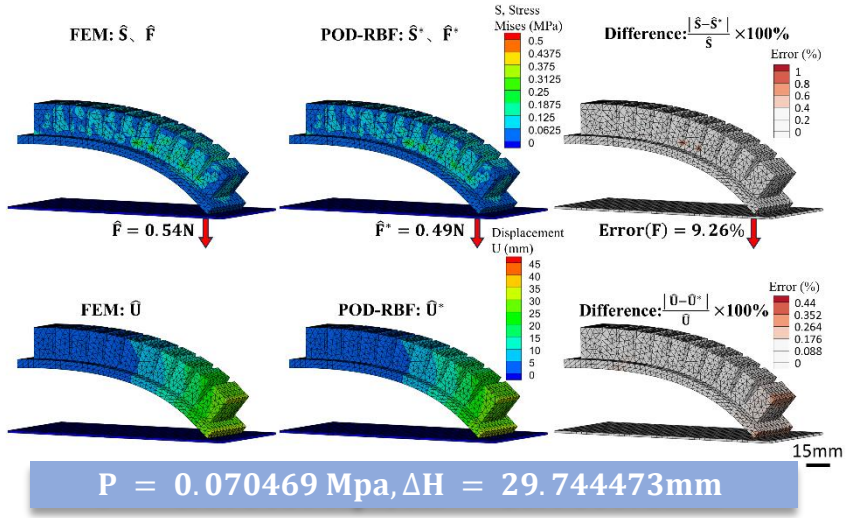

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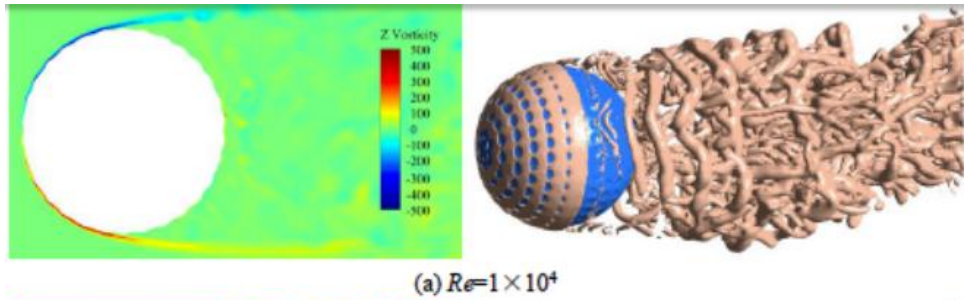
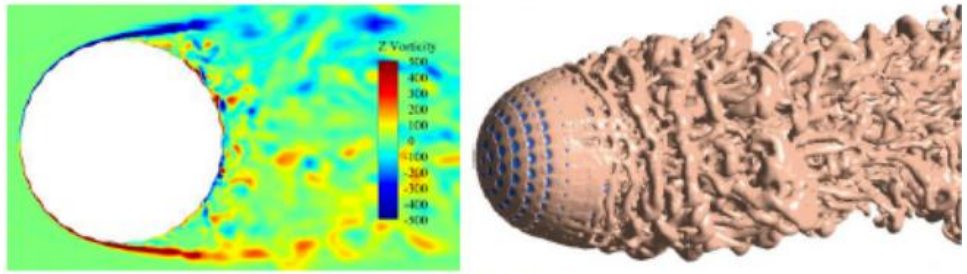
流动控制与减阻设计



(a) Re=1×10⁴



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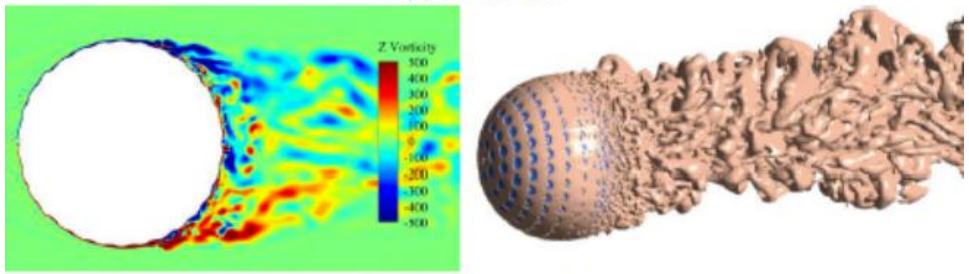
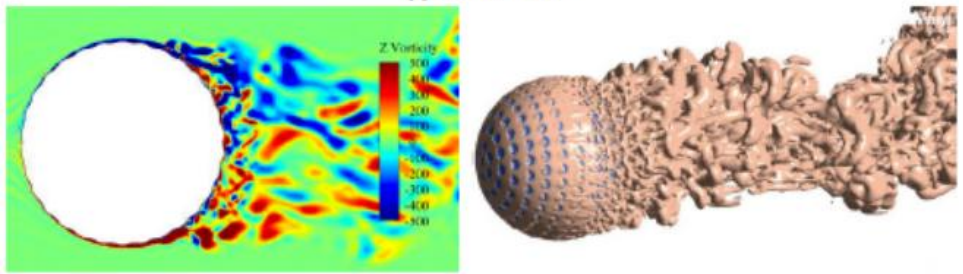
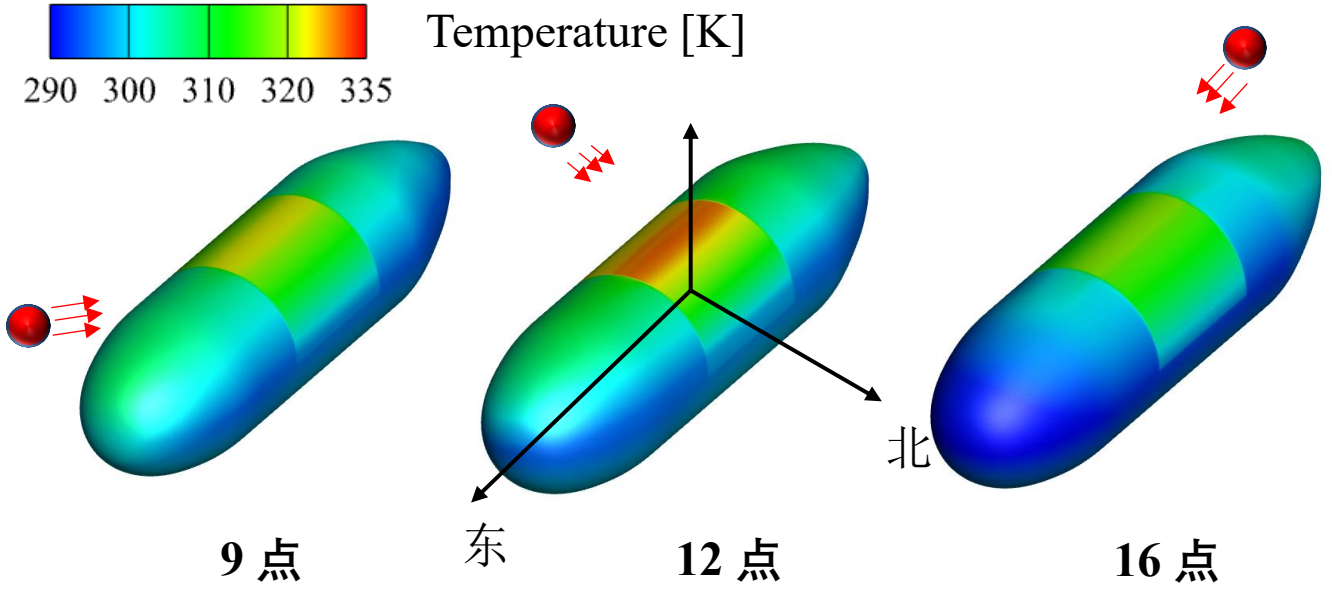


(c) Re=7.5×10⁴



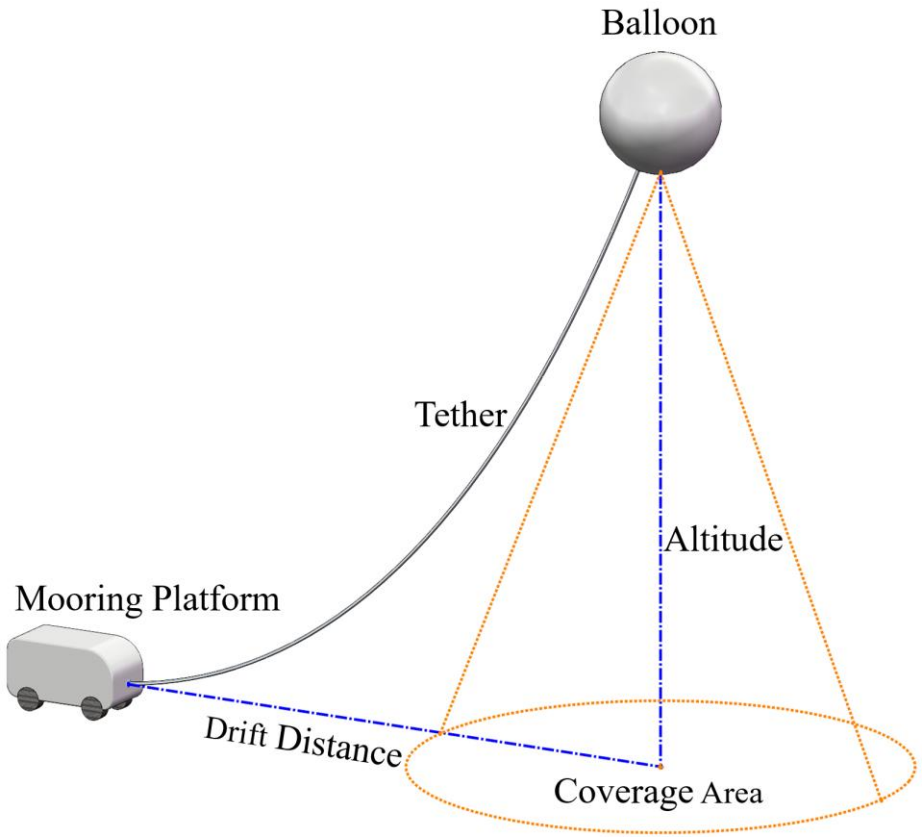
(d) Re=1.1×10⁵

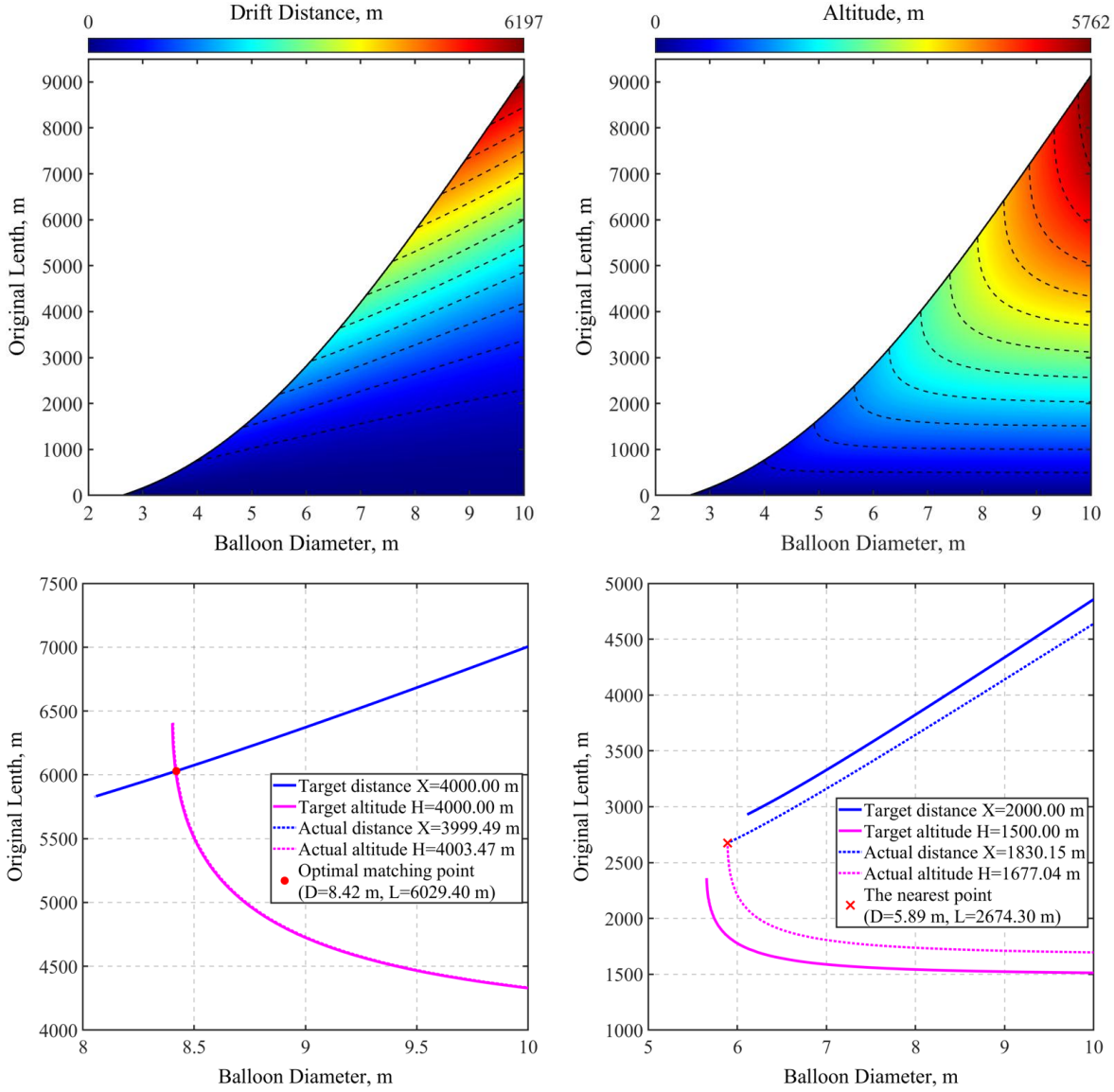


9 点　　12 点　　16 点

Fig.6 35m airship

系留气球升空过程模拟





Ni, Z., Zhu, S., Song, J., Dou, S., & **An, N.*** (2025) *Under Preparation.*

资源与研究特色

- 超算资源：北京，上海，济南国家超算，课题组工作站;
- CAE软件：ABAQUS，ANSYS Fluent
- 编程语言：Python，MATLAB，Fortran，C++;
- 开发与集成平台：TensorFlow，Keras，Isight，自研优化平台;
- 致力于发展和应用最先进的分析计算和仿真技术解决工程中的实际科学问题。

经费来源和合作伙伴

- 国家自然科学基金委：青年基金、国际合作与交流项目；
- 国家留学基金委员会：联培博士项目、访问学者项目；
- 欧盟委员会：意大利特伦托大学 University of Trento；
- 四川省科技厅：省自然科学基金
- 机械结构强度与振动国家重点实验室（西安交通大学）；
- 工业装备结构分析国家重点实验室（大连理工大学）；
- 工程仿生教育部重点实验室（吉林大学）；
- 企业伙伴：中国空间技术研究院西安分院、西北工业大学、陕西恒巨软件、上海鉴创、江苏凝视等。

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